The evolution of systems-integration capability in latecomer contexts: the case of Iran's thermal and hydro power generation systems

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Abstract

This study concerns building capabilities within the electricity sector of Iran, a developing country. It focuses on two areas of high-technology development, hydro electricity generation plants and thermal electricity generation plants, and investigates the accumulation of local capabilities to undertake large and complex development projects in these two areas. The empirical aim of the thesis is to analyse how far the local capabilities have advanced and what can be done to enhance them. The business of engineering and developing complex electricity generation systems, such as hydro and thermal power plants, is an example of high-value high-technology capital goods industries (sometimes referred to as CoPS in the innovation studies literature). This literature suggests that systems integration is a core capability of leading suppliers in CoPS industries. Most studies of capability building at the firm level in latecomer contexts, however, have focused on mass-manufacturing firms rather than on project-based ones. The CoPS literature, on the other hand, has investigated the concept of systems integration capability within the context of developed economies. Therefore, this research aims to examine latecomer systems integration capability (LSIC) in these two CoPS areas in Iran to develop our understanding of the nature and evolution of LSIC.

This research is carried out as an exploratory case study, combining some elements of latecomer theory, systems integration and capability theory to develop the analytical framework for the study. The framework is then applied to evidence gathered from two major Iranian systems integrators that lead engineering and development activities involved in the construction of power plants. Evidence is gathered on the evolution of micro-level attributes, including people, knowledge, processes and structures, underlying LSIC, along with changes in products and outcomes of systems integration activities. These categories of evidence are combined with the evidence on the internal context of the firms and their external environment to reveal their achievements in the accumulation of LSIC, and to understand the dynamics behind the evolution of LSIC.

The analysis of this thesis shows how the two Iranian firms entered into the business of systems integration of power plant systems, and have gradually built higher levels of LSIC, allowing them to succeed in competitive local and overseas markets, and to diversify into local markets for other complex projects. Nevertheless, there have been imbalances, spurts of rapid capability growth, periods of falling behind in specific areas of LSIC, close connections and relationships (amounting to a co-evolution among LSIC areas), and major investments and strategies to remedy imbalances, and to sustain the firms' progress. This thesis also attempts to explain these complex variations in the evolutionary paths of LSIC. In addition to contributing to the latecomer capability literature, this research suggests some policy and business strategy implications.

توانا بود هر که دانا بود

Capable is he who has knowledge

Shahnameh (The Epic of the Kings)
by Hakim Abolghasem Ferdowsi, 1010 CE

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3D	Three Dimensions
ABB	Asea Brown Boweri
ASEAN	Association of Southeast Asian Nations
BOO	Build, Operate and Own
BOP	Balance of plants
BOT	Build, Operate and Transfer
CC	Combined Cycle plants
CCG	Combined Cycle Gas plants
CEO	Chief Executive Officer
CoPS	Complex Product Systems
COx	Carbon Oxides
DoD	Department of Defence
EFQM	European Foundation of Quality Management
EIA	USA's Energy Information Administration
EMAN	Engineering & Manufacturing division of Mapna
EP	Engineering and Procurement
EPC	Engineering, Procurement and Construction
GDP	Gross Domestic Product
GE	General Electric Company
HEC	Harbin Engineering Company
IEA	International Energy Agency
IEA	International Energy Agency
IMIM	Iran's Ministry of Industry and Mines
IPDC	Iran Power Development Company
IT	Information Technology
kV	Kilo Volts
kW	Kilo Watts
LSIC	Latecomer Systems Integration Capability
MD2	Mapna Development Company II
MHI	Mitsubishi Heavy Industries Company
MOE	Ministry of Energy
MTS	Mapna Total Solution
MW	Mega Watts
NIAM	Mapna's standard design for gas power plants
NOx	Nitrogen Oxides

O&M	Operation and Maintenance
ODM	Own Design Manufacturer
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
OPM3	Organisational Project Management Maturity Model
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institution
PMP	Project Management Professional
R&D	Research and Development
RBV	Resource-based View
SI	Systems Integration
SIC	Systems Integration Capability
SUT	Sharif University of Technology
Tavanir	Power Generation, Transmission and Distribution Management Company of Iran
UNCTAD	United Nations Conference on Trade and Development
US	United States of America
US DoE	USA's Department of Energy

Acknowledgements

Other researchers might agree with me that the journey towards a PhD has great potential for learning, and its process and findings are probably more original than the thesis itself. Mine was particularly bumpy, making it painful at times but memorable and above all enriching.

I had an admission in Public Policies for Information Technology from Carnegie Mellon University, and was preparing to leave for the United States when I heard about Sharif-SPRU joint PhD program. It seemed to me that it has a secure financial base and I could travel more often to Iran. However, neither of these perceptions held true later. Within this program, I chose a subject close to the interest of my sponsor, Iran's Ministry of Energy (MoE). When I went back to Iran after my first visit to SPRU, I realised that the financial scheme in the MoE had been cancelled. Shortly after, the Sharif-SPRU program was also cancelled. While I was searching for new financial resources in Iran to continue with SPRU, my supervisor moved to CENTRIM after 25 years of working at SPRU. I was left with the choice of either finding another supervisor or moving to CENTRIM. Very eager to continue with him, I chose the latter. This choice would reveal some of its advantages later. The sudden, temporary closure of the British Embassy at that time introduced new uncertainties, causing a delay of at least six months. I believe these few instances are enough to draw a picture. It is only now that I can realise the impact of some of those events on my understanding of life and on my capabilities. I am not sure about what I would have done if I had gone to Carnegie Mellon, but I am sure I would have missed the chance to meet and work with some amazing people and would have not developed some valuable friendships. My sincere thanks go to people and forces who deliberately or otherwise contributed to this journey.

My lead supervisor, Prof.Mike Hobday, was always passionate, generous, remarkably punctual, and a continuing source of hope and new ideas. I had the chance to be his last PhD student as he retired one week after my viva. My second supervisor, Dr.Tim Brady, joined us later but was very helpful in the final stages. Prof.Howard Rush and Dr.Andrew Davies, as my examiners, challenged me from new perspectives and provided valuable suggestions. Dr.MohammadReza Arasti at Sharif introduced me to the MoE and helped me secure the initial funds. Dr.Ali Kermanshah at Sharif supported me through out the whole journey, helped me secure a large portion of the finance through another scheme at the MoE in the later stages, and used his contacts to link me with FARAB. Dr. Sheikholeslam and Dr.Ghazizadeh showed a remarkable level of support in the MoE. Prof.Ali Mashayekhi at Sharif used his contacts to connect me with Mapna and pushed my case in the company to attract some financial support. Mr.Hajirasoliha, Dr.Hamedi, Mr.Najimoghaddam, Mr.Hooshyar and Mr.Khamene were very helpful during the fieldwork. Finally, I should thank all my colleagues at CENTRIM especially Steven Flowers, the head of Research Students Division, and Louise Streeter, administrator of CENTRIM, for being always supportive.

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Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to his or any other university for a degree, and does not incorporate any material already submitted for a degree.

Signed

Date

1. Chapter One: Introduction

1.1 Background to the study

Iran is a Middle Eastern country which was categorised as an upper middle-income developing economy by the World Bank in 2010. The country is endowed with plentiful natural energy resources, has a significant industrial base, a relatively well-developed science and technology infrastructure and a good human development position (UNCTAD 2005). Some of the revenues from its oil exports are spent by the government on developing the economy. Since the 1978 Islamic Revolution, Iran has faced many political challenges, prohibiting it from developing reliable linkages with international sources of science and technology.

However, Iran has a fairly well-developed and integrated electricity network, providing access for more than 98 percent of its population, a figure well above the average in developing economies. The network is also connected to neighbouring countries, allowing for a regular exchange of electricity. For instance, 70 GWhs of electricity energy was exchanged in 2009 through these connections, 70 percent of which was net export. As of January 2010, Iran had 56817 MWs of installed electricity generation capacity, making it number 17 in the world and number one in the Middle East and West Asia in this respect (US Energy Information Administration, 2010).

One intriguing aspect of the progress in Iran's electricity sector is the extent of its reliance on local capabilities. In addition to undertaking projects, Iranian companies appear to be involved in the engineering and manufacturing of complex product systems[1] such as turbines, generators and transformers. Officials claim that local firms are capable of providing more than 90 percent (in terms of value) of products and services required for the development of the local sector.[2] The official figures also indicate that the export value of related services and equipment by local firms reached over US$ 3 billion in 2010 (Interview with the Deputy for Electricity, Ministry of Energy, on 2011/03/16).[3]

The existing literature on capability building in successful developing economies is largely focused on high-volume manufacturing, consumer goods and component sectors (see for example Hobday 1995; Ariffin and Figueiredo 2006; Chuang 2008). The few studies that focus on high-value capital goods industries (for example Hwang 2000; Lee 2001) often reveal failures or poor performances in creating a competitive sector, indicating the perils

[1] The term 'complex product system', or CoPS, has a specific meaning in the innovation literature, which is discussed below.
[2] Speech by Iran's Minister for Energy at the opening ceremony of Ghaen CCG plant in March 2010.
[3] http://news.moe.org.ir/vdcg3x9x.ak93q4prra.html (in Persian).

of extrapolating the experience and frameworks of catch-up from other sectors. The overall progress in Iran's electricity sector, nevertheless, suggests that certain levels of capabilities have been formed in the local firms that underpin success in local and overseas markets. It is therefore interesting to research the nature of the capabilities that appear to have emerged in this context, to see how far they have advanced, and to ascertain what can be done to enhance them further. Despite the importance of indigenous capabilities in the long-term development of the electricity sector in Iran, and perhaps in other developing economies, these issues have not yet been tackled by researchers investigating Iran's industrialisation process, or indeed the progress of other nations in this area.

The systems incorporated into large-scale projects in the electricity sector show the characteristics of high-technology capital goods, sometimes referred to as complex product systems (CoPS) in innovation studies (Davies and Hobday 2005). The literature on CoPS suggests that systems integration capabilities are at the technological core of this business and are a chief source of operating competence, innovative capacity and competitive advantage among leading suppliers (Hobday, Davies et al. 2005). The research on systems integration capabilities in CoPS is, however, largely based on evidence from developed economies (see for example Prencipe 2003; Brady and Davies 2004). Firms in developing countries, or 'latecomer' firms, by definition operate in a different context and cannot enjoy the technological opportunities open to their counterparts in developed economies, raising serious questions over whether catch-up is possible in CoPS.

In addition, the well-recognised differences between CoPS and mass-manufacturing industries (Hobday 1998), including the extent of engineering and customisation involved in each CoPS system and project, suggest that existing frameworks for the evolution of latecomer capabilities might need significant modifications in order to explain the birth and growth of capabilities in the latecomer CoPS context. Furthermore, the few examples of existing research on CoPS in developing economies have taken place in countries that have a different economic and technological history to Iran, which, as noted above, faces political challenges in relation to accessing international sources of knowledge and technology. These contextual factors are likely to shape the challenges and opportunities facing Iran, as contextual factors do in other nations.

1.2 Research objectives

Considering the above background, this study pursues the following objectives:

Firstly, the thesis explores the achievements of firms in Iran's electricity sector in building systems integration capabilities, and aims to understand their progress and position in the catch-up process. The study aims to examine changes in the status of capabilities over time, and the resulting business impacts of the changes.

Secondly, the research examines the pathways through which systems integration capability has evolved in the context of electricity generation systems in Iran. In doing this, the thesis explores the dynamics behind the evolutionary paths in terms of the internal factors, external forces and interactions between them that have shaped these paths.

Thirdly, the study investigates the internal (e.g. trial-and-error learning) and external (e.g. knowledge transfer agreements) sources that Iranian firms have relied on to build up their systems integration capability. In particular, the research focuses on relationships with foreign sources, and examines how the combination of internal and external sources has changed over time in accordance with the development of local capabilities.

Fourthly, from a theoretical perspective the purpose of the thesis is to introduce and develop the concept of latecomer systems integration capability (LSIC) in CoPS. The study seeks to understand the composition of LSIC, the pathways of its evolution, the business outcomes of LSIC, and the mechanisms for building it. The research also touches on a comparison between the evolutionary paths of LSIC and other paths in the latecomer literature to see whether and how it differs from such paths. The thesis hopes to provide a framework that might be useful in examining progress in high-technology capital goods industries in developing economies.

The above objectives can be crystallised into the following main questions and key sub-questions:

What is the nature of latecomer systems integration capability (LSIC), and how has it evolved over time?

1. What are the constituent parts of LSIC?
2. What are the depths and levels of these constituent parts? And how have these changed over time?
3. What have been the pathways and mechanisms of capability development (e.g. between firms and across different parts of capability)?
4. How did the building of LSIC take place? For example, what inputs were needed? What were the transformation processes? What were the outputs in terms of, for instance, new or improved systems, amended designs, market confidence, expanded

technological possibilities and improved relationships with suppliers and customers?

5. What have been the outcomes of LSIC building, for example in terms of business performance, product/system development, and value chain position?
6. What are the remaining gaps and limitations of LSIC building, and how can we explain differences in pathways and achievements among firms?

Answers to these questions will hopefully shed light on the drivers that have motivated firms' strategists and external policy makers to build LSIC, the types of difficulties that have confronted the building of capabilities, and the ways in which these difficulties have been addressed.

Theoretically, this study hopes to extend the current literature on capability building in the latecomer context by defining, identifying and elaborating key aspects of LSIC, and by relating the findings with regard to the evolution of LSIC to other parts of the literature. From a practice perspective, the thesis hopes to provide suggestions for policy makers and business strategists in Iran to help them further develop local capabilities. As far as wider implications are concerned, the study hopes to generate some new insights for other developing economies that may be considering initiating or enhancing local capabilities in their electricity generation industries.

1.3 Research methods

Chapter Five provides a full explanation of the study's research methods and research design, including the reasons for the choice of research strategy, the choice of sample firms, details of the conceptual framework and relevant empirical data that needed to be obtained from Iran as a developing economy. The thesis is exploratory in nature, identifying a new concept and examining the dimensions of LSIC that are little known, rather than measuring the rate or frequency or testing propositions previously identified in the literature. The purpose of exploratory study is to generate new empirical evidence where such evidence is lacking, to generate relevant concepts, frameworks and new empirical categories, and to identify plausible propositions for further study. Exploratory investigation allows several sources of evidence to be examined, and the longitudinal nature of the case studies in this research promises to generate an improved understanding of the phenomenon under study.

At the core of the empirical research are in-depth, explorative case studies of the two main Iranian firms, Farab and Mapna, engaged in the business of managing, producing, designing and implementing electricity generation systems within Iran. Electricity generation systems have been chosen as the focus of this study mainly because they are at the core of electricity networks in Iran and other countries. Furthermore, they are more complex[4] and more costly in comparison to the transmission and distribution systems.

Successive electricity generation projects have been of critical importance to the provision of reliable electricity services in Iran and, as such, to the overall economic development of the country. Electricity consumption has grown at an average of 8 percent annually over the past decade in Iran, and its growth is expected to continue at around the same rate over the next decade,[5] requiring large investments in building new generation plants. Iran was number two in the world, after China, in terms of the amount of new electricity generation capacity that was synchronised with its grid in 2009 (IEA 2010). Among the various electricity generation systems, this thesis focuses on thermal and hydro electricity technologies. These two types of generation systems account for 99 percent of the overall electricity generation capacity of Iran (Tavanir 2009), while the remaining one percent is based on other renewable sources, such as wind and geothermal systems. The focus of future investments will remain on thermal and hydro systems, although the government's target is to increase the share of other renewable systems to ten percent of the total electricity generation capacity of Iran by 2025.[6]

Among the Iranian firms involved in the systems integration of power plant projects, Mapna and Farab have been chosen as case studies. These firms were established in the 1990s and had been operating for less than 20 years at the time of this research. These two firms were the only local systems integrators of hydro and thermal generation systems until 2008, when the government started supporting the entry of new local competitors. The new contractors were either former subcontractors of Mapna and Farab, or were newly-established companies created by former employees of these two firms. The newcomers, however, appear to still be pure project management companies, lacking engineering and manufacturing capabilities, and have not yet completed any major

[4] The notion of product complexity refers to several product dimensions, including the quantity of sub-systems and components, the range of knowledge and skills involved, the degree of customisation of sub-systems and components, and the intensity of involvement of other suppliers in design, engineering and delivery of the system (Hobday, 1998: p3).

[5] This analysis is based on the annual reports and statistics published by Tavanir during the period from 1999 to 2010. These reports are available in both Persian and English languages on the website of Tavanir at http://www.tavanir.org.ir/latin. Tavanir (Iran Power Generation, Transmission and Distribution Management Company) is a holding company for organising, directing and managing the government's assignments in the operation and development of the electricity sector in Iran. Tavanir governs the state-owned companies involved in the generation, transmission and distribution of electricity all over the country. It also governs the state companies that are engaged in the formulation and implementation of plans for developing the sector. By time of the start of the privatization process in 2004 and the entrance of private investors into the electricity generation sector in Iran, Tavanir had established the National Grid Company and had set up a wholesale electricity market. In addition to the above roles, Tavanir acts as a government agency proposing the rules, developing the policies and supporting the growth of the electricity sector (Changes to The Articles of Incorporation of Tavanir, The Government's Office, 2002).

[6] This analysis is based on the objectives defined by Iran's Ministry of Energy to meet the requirements in Iran's '20-Year Vision Plan'. Iran's Expediency Council published this plan in 2005. It sets out the 20-year strategy of the country for becoming the major player in the region, and defines the overarching policies that the government should follow in this direction.

projects. Farab and Mapna, in contrast, have a long history in building LSIC and appear to have accumulated a wide and deep range of LSIC.

As discussed in Chapter Three, the research selects and combines concepts from three largely separate bodies of literature in order to build a framework for analysing LSIC accumulation. These bodies of literature are systems integration in CoPS, latecomer firm theories, and capability analysis from the strategy literature. Although none of these bodies of literature on their own provides a framework for understanding the issues of LSIC, concepts and insights provided by each of these bodies of literature are integrated in Chapter Five to develop an initial conceptual framework to guide the fieldwork of this study and to provide a way of systematically assessing the actual evidence gathered during the field research. In the conceptual framework, LSIC is broken down into three core constituent parts namely, latecomer functional SIC, latecomer project SIC, and latecomer strategic SIC. A set of simple staircase models is developed for LSIC, depicting levels of depth for each constituent part. The models are used for benchmarking the evidence, and might be supported, refuted or refined in doing so.

The empirical research gathers in-depth data on changes in LSIC, examining the micro elements of the latter at the levels of people (e.g. engineers and managers) and teams, knowledge accumulation and organisational structures. The field research also looks for data on the drivers and motivations behind the evolution of LSIC, as well as the inputs into the processes of capability evolution, the transformation mechanisms involved (e.g. official knowledge transfer agreements and more informal arrangements), and the outputs of the process, including changes in the products and systems as well as changes in the market possibilities. This integrated approach hopes to generate an understanding of LSIC within the dynamic context of the firms and their external environment.

1.4 Structure of the thesis

This thesis contains nine chapters. Chapter Two presents a brief history of industrialisation in Iran and examines the overall development of Iran's electricity sector to place the study within its national context. It also contains a preliminary assessment of general aspects of technological progress in the Iranian electricity sector to provide a background for the study of the emergence and growth of LSIC.

Chapter Three reviews the extant literature to assess its potential contributions to the aims of this thesis. The assessment of the three previously mentioned bodies of literature shows that they are largely disconnected, and only offer partial perspectives on the issues of LSIC. Therefore, the chapter identifies elements in each body of literature that might contribute to building a conceptual framework for this study.

In line with the emphasis of the existing literature on the differences in systems integration across CoPS sectors, Chapter Four investigates systems integration in the global context of hydro and thermal electricity generation systems. This chapter generates some provisional insights into the differences between leadership and latecomer systems integration capabilities, and indicates some of the challenges and opportunities that latecomer firms might face in developing LSIC. This sector-specific awareness helps operationalise LSIC for the empirical research.

Chapter Five develops the research design and methodology. It combines the insights, concepts and frameworks identified in the previous chapters to build a provisional definition of LSIC. It then provides an approximate framework to enable the exploratory study of LSIC in Iran's electricity generation industry, pointing towards three core constituent parts of LSIC, namely latecomer functional SIC, latecomer project SIC, and latecomer strategic SIC. It provides a justification for the two empirical case studies of the two Iranian systems integrators, Farab and Mapna. The chapter also discusses the data sources, the details of the fieldwork process and the processes for data analysis.

Chapters Six and Seven present the evidence and findings on the origin, composition and evolution of LSIC in our two case study firms. These chapters show how LSIC evolved from small beginnings in low-cost project management within the local electricity generation market to having a significant position across all three core constituent parts of LSIC to underpin success in overseas markets. The analysis reveals a picture of the behaviour, progress and outcomes in LSIC embedded in the dynamism shaped by factors internal to the firms and by external forces.

Chapter Eight compares the evidence and findings of one case study with the other in terms of inputs, transformation processes and achievements in the evolution of LSIC. The aim of this cross-case comparison is to reveal additional insights into the issues of LSIC. In an attempt to understand the complex firm-specific variations observed in the progress of LSIC in Farab and Mapna, the chapter looks beyond the three main bodies of guiding literature described above. In the search for additional material to help understand the phenomena witnessed, the study applies a slightly modified version of Hughes's framework (Hughes 1983), which was originally developed to make sense of commonalities and differences in the expansion of electricity networks in industrial nations. This additional exploration of the literature resulted from a need to try and explain the differences and similarities in patterns of LSIC across the two firms, and their underlying causal factors.

Chapter Nine summarises the empirical findings, revisits the provisional definitions of concepts in light of the evidence, and discusses the nature and evolution of LSIC in Iran. It compares the evolutionary path of LSIC with other existing paths in the latecomer literature, and suggests some explanations for these differences. The chapter also discusses the limitations of this research and provides some implications for research, policy and business strategy.

2. Chapter Two: The history and development of the electricity sector in Iran

This chapter combines a brief review of the history of industrialisation in Iran with an assessment of the overall development and technological progress of the electricity sector of the country to place the thesis within the local context and provide some background to the birth and growth of LSIC. It highlights the major shifts in industrialisation policies of the country, reviews the impacts of the 1978 Revolution on the progress, and provides a broad view on the current position of the economy.

The data for this chapter has been gathered from various sources, including official reports and statistics, published books and journal articles and conference proceedings. The majority of information sources on the progress of the electricity sector in Iran are in Persian. The chapter indicates that the government has always played a key role in the industrialisation of the country. It also shows that the focus on lightweight consumer goods industries at the beginning of the industrialisation process progressed to intermediate and capital goods industries in the final years before the 1978 Revolution. However, local industries at this time were still largely confined to the assembly of products. After the Revolution, the local chains of suppliers, which had been poorly developed in the intermediate and capital goods industries, grew and more attention was given to expanding technological capabilities with a view to promoting exports.

The chapter shows that within this broad context of industrialisation, before the Revolution local capabilities in the electricity sector developed from learning how to operate the infrastructure to manufacturing equipment and managing projects for the technologically simpler parts of the network, namely distribution. After the Revolution, local capabilities were extended to cover the conduct of research on operational problems, the manufacturing of complex equipment for electricity generation and transmission projects, and the management of such projects. Local firms also started to export their products and services into overseas markets.

The chapter is organised in three sections. The first part briefly reviews the history of the industrialisation process in Iran. The second section looks into the origins of the electricity sector in Iran and illustrates how it has developed over time with a focus on its technological progress. The conclusion summarises the chapter and discusses some research issues arising from this review.

2.1 A brief review of the history of industrialisation in Iran

In 1900, Iran was a non-industrial country with less than ten percent of its GDP generated by the industrial sector (Floor 1984). The shift to a new economic structure started when a strong central government was established in 1925. Roads were built, a railway network was constructed, a national bank was founded and modern schools were set up at several levels of education. Darolfonon had already been established in 1851 as the first modern higher education institution in Iran, but had developed slowly over time. In 1934, Tehran University was established as the first modern university in the country. During the first half of the 20^{th} century, progress was focused on modernising the traditional economy, e.g. agriculture and textiles. The government played an important role in the modernisation and industrialisation efforts of this period by incentivising developments and helping private firms to finance the process, making Iran a very interesting example in the Middle East of a state-directed effort towards industrialisation (Grunwald and Ronall 1960).

Between 1947 and the Islamic Revolution in 1978, the government implemented a number of national development programmes to speed up economic progression. The focus of the first and second development plans (1948-1962) was on modernising the agriculture sector. However, the three programmes that were implemented between 1963 and 1976 aimed to increase the share of industry in the economy. Over this period, a number of organisations such as the Industrial Development Organisation were established to support the industrialisation process (Ghanbari and Sadeghi 2007). In the late 1960s, Iran's modern manufacturing industries had been expanded to include passenger cars and home appliances; however, local firms were primarily involved in the assembly of final products, making them heavily reliant on the import of parts and intermediate inputs (Esfahani and Pesaran 2009). During the time of the fourth development plan, industrial progress gained more speed when the government increased its financing, and cheap labour began to emigrate from rural areas to cities as a result of the Land Reform Policy. On the other hand, the dependency of the development plans on oil exports had gradually risen, so that oil revenue provided 96 percent of the financial resources for the fourth development plan (Ghanbari and Sadeghi 2007).

During the eight decades of industrialisation efforts before the 1978 Revolution, Iran's government pursued a strategy of import substitution. The early plans aimed to develop the consumer goods industries; however, from 1968 onwards those developments were combined with investments in intermediate goods industries and, gradually, in the capital goods sector (IMIM 2004). For instance, Machinsazi Arak started its operations in 1972 to manufacture and install some components and machines for industrial plants. The 1978 Revolution, however, brought considerable changes to the economic development of Iran.

During the eight-year war with Iraq (1980-1988), Iran's agriculture sector gained more importance, and industrial investments concentrated on producing high consumption goods for the local market. Due to the advent of embargos during the war, some of the existing industrial capacities in Iran were deployed and, in some cases, extended to the manufacturing of military equipment. When the war ended, the government resumed implementing national development plans. The post-Revolution plans were multi-perspective, compared to the mere economic focus of the pre-Revolution plans (IMIM 2004).

Four five-year development plans were implemented after the war until the end of 2010. Three themes are recognisable in the post-Revolution plans. Firstly, the priorities have gradually shifted to the intermediate goods and capital goods industries with a view to meeting local demands and exporting excess capacities. Secondly, the strategy of import substitution was combined with some efforts to promote exports. Thirdly, the experience of manufacturing equipment during the war has inspired investments in local technological capabilities, and local supply chains have therefore expanded from assembly to engineering and product development (SUT 2009).[1] The profile of local manufacturing firms has diversified from predominantly light industries, such as textiles and food, into rail and sea transport industries, the manufacture of equipment for electricity and petrochemical plants, and farming and construction machinery (IMIM 2004). The post-Revolution plans, however, have inherited the high dependency on oil revenues from their pre-Revolution ancestors. This dependency can have a significant effect on the overall economic progress of Iran when oil prices fluctuate in commodity markets. For instance, the record falls in oil prices between 1997 and 1999 caused a shortage of foreign currency in the local market in Iran, temporarily halting some projects while opening up new opportunities for other local firms (SUT 2009).[2]

Based on statistics published by the World Bank, Iran was an upper middle income country in 2010. The population of the country has doubled since the 1978 Revolution, reaching 72.6 million in 2008 as a result of a baby boom in the 1980s. The literacy rate has also increased from 50.8 percent in 1978 to 86.9 percent in 2008 despite the sharp

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[1] Designing SAMAND as a nationally produced passenger car was probably the boldest attempt to expand the local capabilities of the civil sectors in the early years after the war.
[2] It is claimed that the shortage of foreign currency was one major reason to justify the development of a local supply chain for passenger cars (interview by Mr. Veise, the former head of IDRO).

increase in the population, indicating that the post-Revolution governments have invested in education.[3]

As Figure 2-1 shows, the contribution of industry to Iran's GDP rose from seven percent in 1959 to 13 percent in 1978, a twofold increase over the 20-year period, accompanied by a sharp decrease in the share of agriculture. In 2007, around 26 percent of the GDP came from the industrial sector, while the agriculture sector had a 13 percent share, indicating the greater attention given by the post-Revolution governments to agriculture. Official statistics indicate that 78 percent of export revenues in 2008 were from crude oil and gas, while industrial exports accounted for only 17 percent of export revenues (IMIM 2007).[4] The data also show that exports of high technology manufactured products[5] stood at six percent of the manufactured exports of Iran in 2007 compared to, for instance, 52 percent of Malaysia's exports and zero percent of Turkey's (WorldBank 2010).

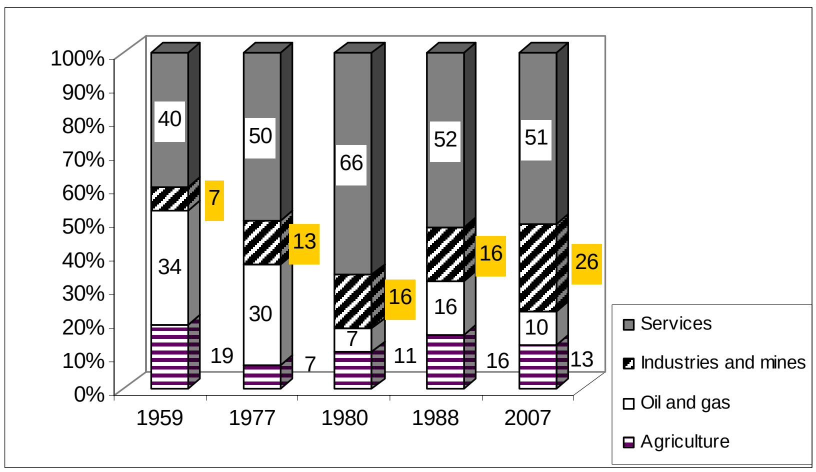

Figure 2-1: Share of each economic sector in Iran's GDP (Source: Statistics by The Central Bank of Islamic Republic of Iran)

2.2 The development of Iran's electricity sector

In 1885, three years after Thomas Edison built the world's first power plant in New York, an electricity generator was installed in Tehran to light the lamps in the royal palace. However, the commercial use of electricity did not develop until 1904[6] with the beginning of the construction of the first commercial power plant by a prominent businessman, Huj Aminozzarb. Although local technicians were employed in his firm, the technical and financial management of operations was in the hands of a foreign engineer. Over the next

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[3] The number of students pursuing higher education in particular has increased over the years, so that while less than half a percent of the population was in higher education in 1978, this had risen to 6.5 percent by 2008 (Source: Economic Time Series Database, The Central Bank of Islamic Republic of Iran). Whether this potential human capital can be deployed effectively by local industries is a different matter.
[4] Less than a half of these export figures are related to petrochemical products.
[5] High technology exports are products with high R&D intensity. They include high-technology products in industries such as aerospace, computers, pharmaceutical and electrical machinery (World Development Report, 2010).
[6] In 1900, another generator was installed in Mashhad to light the holy shrine of Imam Reza.

six decades, private firms undertook the majority of investments to expand the coverage of electricity in the large cities of Iran. The Islamic Revolution in 1978 and the end of the eight-year war with Iraq in 1988 have been the major turning points in the development of the sector.

2.2.1 Before the 1978 Revolution

As discussed in the previous sections, several national development plans were implemented between 1947 and 1978. From the perspective of the electricity sector,[7] the major aims of these plans were to broaden geographical access to electricity, to increase electricity supply, and to reduce electricity prices.[8] At the end of the first plan (1947-1954) a contract was signed with Alstom to provide four steam turbines to Iran. In this contract, a group of local technicians and engineers were sent abroad to learn the technical and managerial skills required for power plant operation.

During the second plan (1955-1962), the first projects to build distribution (20kV and 63kV) and transmission (132kV) networks were started and the construction of the first hydro power plant in the country was contracted to US and French firms. Iran's Electricity Development Organisation was established in 1962 to oversee the rapid development of the sector and to replace the municipalities in issuing development permission. Private companies had a dominant role in the sector at this time. For instance, 32 private firms were in the business of generating and distributing electricity in Tehran.

Due to the economic aim of making a rapid shift from agriculture to industry, in the third development plan (1962-1967) a separate section was dedicated to policies specific to the electricity sector. The major change in this period was the nationalisation of industries in 1965 with the intention of ensuring that the electricity sector would develop in synchronisation with the broader industrialisation objectives. The newly-established Ministry of Power and Water organised ten regional electricity companies to create an integrated approach to the development and operation of the sector across the country. During the period of this plan, electricity supply was expanded to be available 24 hours a day. Several private firms were established to manufacture equipment for the distribution networks; such equipment is technologically simpler than transmission and generation equipment. IRANTRANSFO Co. was one such firm, founded in conjunction with Siemens

[7] In this chapter, the term 'electricity sector' is broadly used to cover the development and operation of all the elements in the network, from electricity generation to the final points of consumption, categorised into three main sections: generation, transmission (and sub-transmission) and distribution (Saadat, 2002). The transmission section is a high-voltage system to transmit electricity from the generation plants to the areas of consumption. Large industrial plants may connect directly to the transmission system. The distribution section is a low-voltage system that connects the consumers to the electricity network. Equipment is technologically simpler in the distribution section compared to the other two sections.
[8] This section draws on MohammadSadegh (1998).

to manufacture distribution transformers. The company has developed over time and currently builds complex high-voltage transmission transformers in addition to its product lines in the distribution business.

During the period of the fourth development plan (1968-1972), the Power Generation and Transmission Company of Iran (Tavanir) was established to integrate the planning, development and operation of the three sections of the electricity sector. In 1966, a training centre was created to provide short-term and on-the job training courses in addition to training new technicians for the operation of the sector. This training centre has expanded over time into a university of technology, offering a wide range of engineering and management programmes tailor-made to the operational needs of the sector. Engineering firms such as MAHAB were also established during this period as joint investments with international engineering firms to provide services to local projects.

During the period of the fifth development programme (1973-1977), a 20-year energy strategy was formulated to meet the growing energy consumption demands of industrialising Iran. A critical part of this plan was the substitution of conventional fossil fuels with nuclear, water, solar and wind energy. As part of this strategy, two nuclear power plants with a total capacity of 2400MWs were planned to begin their operation in 1980. Since the 1978 Revolution, however, the country has faced political opposition to finishing the first plant. Throughout the period of the fourth and fifth plans, further private initiatives were undertaken to manufacture a wider range of equipment for distribution projects and to manage such projects.

2.2.2 Between the Revolution and the end of the eight-year war with Iraq

Foreign technicians and engineers who were involved in projects in the electricity sector left Iran either on the eve of the Revolution or immediately after it, under international pressure. The assets belonging to some local firms were also seized by the new revolutionary government. These developments caused the progress of projects in the electricity sector to be temporarily halted, leading to an extensive effort after a few years by the Ministry of Energy to establish new companies or revive existing ones to resume projects in the sector. The situation was exacerbated when Iraq invaded Iran two years after the Revolution, resulting in an eight-year war and destruction of infrastructure. The desperate strategy of Saddam Hussein to bring the war into Iranian cities in the final years of the war led to wider destruction and regular electricity blackouts in the country.

The reliance on local capabilities for undertaking projects and manufacturing equipment in the electricity sector was broadened during the war. The development of local manufacturing capabilities, however, largely focused on the transmission and distribution networks. In 1983, MATN was established as an applied research organisation for research into the technological challenges of operating the sector.

2.2.3 After the war

A ten percent increase in annual electricity consumption was projected to take place during the period of the first development plan after the war (1989-1994). The economic feasibility of using local capabilities was the major driver behind initiatives to increase the share of local involvement in projects during this period. Several investments were undertaken to manufacture equipment for transmission networks and power plants. Farab and Mapna were established during this period to act as prime contractors for local hydro and thermal power plant projects. The government also supported local contractors in the management of distribution projects to upgrade their capabilities and undertake transmission projects (MOE 2004). The next section discusses these technological developments in more detail. Enhancing local capabilities resulted in considerable reductions in Iran's dependence on foreign currency for the development of the sector. For instance, foreign currency spent on hydro power projects dropped from 1000 US$ per kW of capacity to 350 US$ per kW over this period (MohammadSadegh 1998).

During the period of the second post-Revolution plan (1995-1999), the expansion of installed generation capacity in the sector allowed for small exports of electricity to neighbouring countries such as Turkey and Azerbaijan (MOE 2004). Iranian firms also started to export services and equipment for electricity projects into regional and African markets. Furthermore, new legislation allowed for private investment in power plants, and the government started to prepare the ground for privatising its assets in the sector.

The third and fourth national plans (2000-2004, 2005-2009) have followed the same broad direction of the second post-Revolution plan, with an emphasis on the generation of electricity by large industries and a larger reliance on private investment for the development of the sector (MOE 2004; Tavanir 2008). The fourth post-Revolution development plan also aimed to renovate the aging infrastructure. Following the growth of private investment in the sector, some investors in power plants showed preferences for buying some equipment and project services from abroad despite the existence of local capabilities. For instance, Mahtab Gostar Co. contracted out its 2000MWs combined cycle plant in 2004 to Siemens (Mahab Gostar Co. website). The imposition of wider trade embargos since early 2005, however, has halted the forging of new deals with international firms.

The following four figures provide an overall picture of developments in Iran's electricity sector since 1967. As Figure 2-2 demonstrates, the total capacity for electricity generation rose on average by seven percent annually between 1988 and 2009, ending with around 56GW of capacity, which gives the country first place in the Middle East and West Asia and 17th place in the world in terms of electricity generation capacity. Figure 2-3 indicates that gas-fired and combined-cycle plants comprise the largest share of electricity generation in the country, while renewable sources, including hydro plants, make up less than 16 percent of the total figure.

Figure 2-4 shows that the size of the transmission network has almost doubled in the past five years. In 2009, 100 percent of the population living in cities and in villages with 20 or more households, as well as more than 90 percent of the rest of the population had access to the electricity.[9] Overall, the electrification rate in Iran was 98.4 percent in 2009, which was much higher than the average of 73 percent in developing countries (IEA 2010). In 2010, Iran had an overall total of US$ 3 billion worth of exports of services and equipment for electricity projects (interview with the Deputy for Electricity, Ministry of Energy, on 16 March 2011).[10]

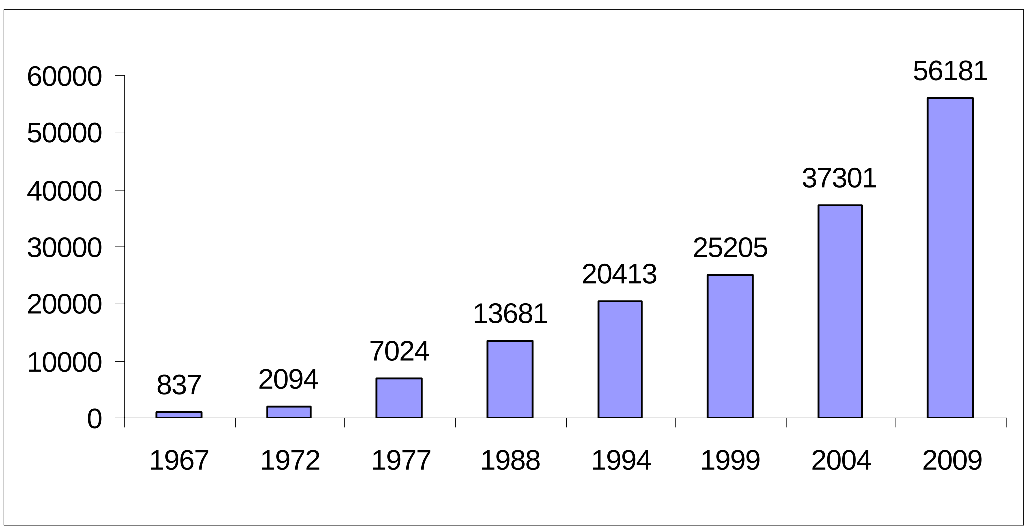


Figure 2-2: Changes in the installed generation capacity of Iran (in MWs) (Source: Statistics published by Tavanir).

[9] High mountain ranges are spread across Iran, creating several broad basins where cities have traditionally been located, surrounded by thousands of villages in the mountain areas. It is costly to reach some of these isolated villages by modern transportation systems, since the only way is to pass through high mountains.
[10] http://news.moe.org.ir/vdcg3x9x.ak93q4prra.html (in Persian)

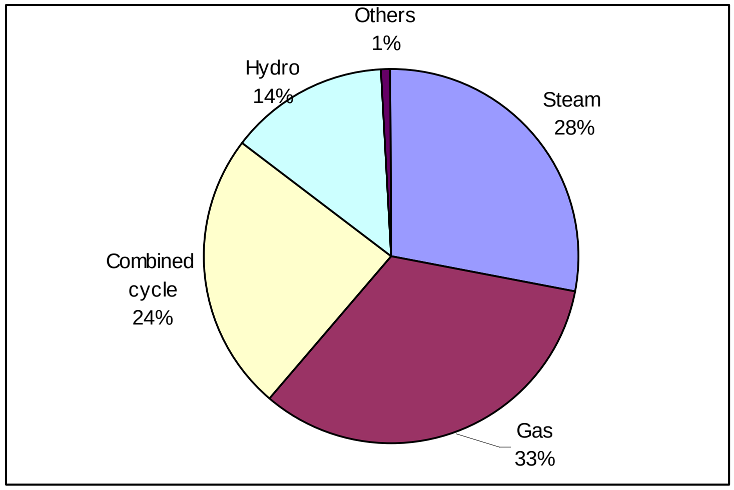
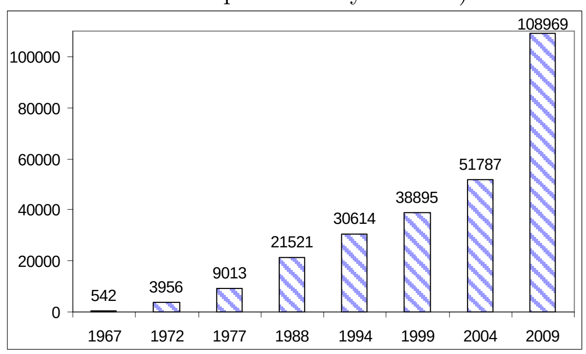


Figure 2-3: Share of various technologies of the total generation capacity of Iran in 2009 (Source: Statistics published by Tavanir).



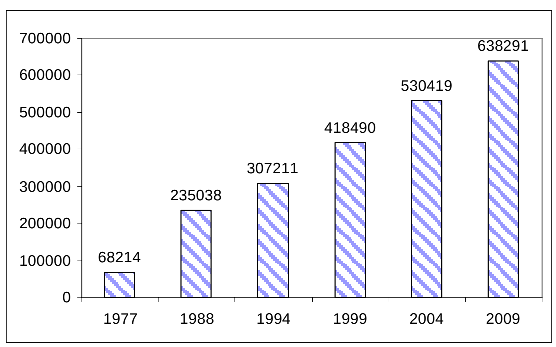


Figure 2-4: Changes in the size of the transmission (left) and distribution (right) networks (in Kms of lines) in Iran (Source: Statistics published by Tavanir).

2.2.4 Key technological developments in Iran's electricity sector after the 1978 Revolution

Although the overall progress has been discussed in the previous section, this section briefly reviews the key technological developments in the sector to provide a background to the origin and evolution of LSIC in Iran's electricity sector.

Transmission systems

Before 1990, these projects were carried out by international firms. These firms usually undertook engineering tasks, supplied the equipment and deployed local contractors for construction and erection of projects. Aside from the switchboards, the other equipment for 63-132Kv stations could potentially be sourced from local suppliers after the war, but the international project firms showed a reluctance to deploy local capabilities (Refan 2003). The Ministry of Energy therefore supported local contractors for distribution projects to upgrade their skills to undertake transmission projects and deploy developed local capacity in projects. Local firms had considerable cost advantages at this time (Refan 2003).

Unlike for 63-132kv stations, few types of equipment for higher-voltage stations (up to 400kv) could be sourced locally at the time. A cost analysis of projects by Tavanir in 1992 revealed that four systems represented around 60 percent of the costs of high-voltage transmission stations (Mehdizadeh 2003). Accordingly, the demand of new transmission stations over the long-term was aggregated by the local state client into a package comprising 25 stations, in order to create incentives for foreign firms to transfer technology to Iran. PARSIAN Co., one of the local contractors that had been upgraded, was chosen as the prime contractor for this package. PARSIAN ordered equipment from overseas firms on the condition that they engage with local firms and perform a share of their engineering and manufacturing activities in Iran. This arrangement turned out to be successful. Today, not only do local firms undertake projects in and manufacture equipment for Iran's market, but also export their services and products into overseas markets (PARSIAN Co. website).

Generation systems

Before 1981, power plants in Iran were built through turn-key projects by international firms such as Siemens, Hitachi, Alstom and GE. In 1981, the Shahid Rajaee steam power plant project was begun in an attempt to develop local involvement in such projects (Mehdizadeh 2003). The engineering and management office for this project was located in Tavanir. The equipment for the plant was classified into several groups based on the extent to which this equipment could be sourced locally. Some arrangements were devised to transfer the technology in feasible cases to local firms (interview with Mr. Mehdizadeh). This project took around ten years to complete and faced many problems in terms of cost management, management of changes in the technical scope, price fluctuations and some other aspects of project management. This experience revealed the complexity of project management in power plant projects to the industry leaders.

In 1992, Farab, a newly-established firm at the time, was invited to participate in the international competition for the expansion of SHAHID ABBASPOUR (KARUN I) hydro power plant. Farab secured its second project in the following year. The firm forged relationships with international firms such as HydroQuebec to learn about project management and project engineering. As the available written history indicates, Farab was provided with foreign engineers over the period of a five-year agreement to supervise local engineers. Farab's policy was to develop a local chain of suppliers by negotiating for technology transfer (Mehdizadeh 2003). Farab appears to have accumulated some capabilities in engineering, design and project management over time. The company has also secured projects in overseas markets, including Kenya, Tajikistan and Sri Lanka (Database of Exports, Office for Economic Studies, Iran's Ministry of Energy).

Similar to the case of transmission equipment, although it was claimed that local firms could provide a wide range of non-core equipment[11] for thermal plants, the use of local capabilities by overseas prime contractors was confined to construction and the manufacturing of very few types of equipment. In 1993, Mapna was established as a prime contractor in this field to reduce project costs and help develop local capabilities. In its initial projects, Mapna undertook project management tasks but bought in some engineering services from Monenco Iran, and purchased core equipment from major international firms as well as a wide range of non-core equipment from local suppliers. As information on the company's website indicates, Mapna has gradually expanded its business from project management to invest in plants for manufacturing turbines, generators and recovery boilers, and has acquired Monenco Iran to build its engineering capabilities. As of 2009, Mapna had 37000MWs of electricity generation capacity already delivered or under construction, some of which was for clients in the region such as Oman, Iraq and Syria (Tavanir 2009).

According to Tavanir, by 2009 all transmission projects in Iran were being undertaken by local engineering and contracting companies, and no foreign company was directly involved in managing hydro, thermal and wind electricity generation projects (Tavanir 2009). Over the past four years, other local firms such as AZARAB and SADID have entered the local market for systems integration of power plants; however, Tavanir's records show that in 2009 these firms had secured few projects and none of their projects had been completed.

2.3 Summary

This chapter has presented a brief history of industrialisation in Iran with a focus on the overall development of the local electricity sector, in order to illustrate the broader context in which local systems integration capabilities have formed and developed in this sector. It has also provided a preliminary view of key aspects of technological progress in

[11] The core equipment of a plant includes the turbine and generator. The rest of the systems are called non-core equipment or auxiliary systems, and provide required services for the reliable performance of core equipment. Examples of non-core equipment include the pressured air system, fire protection systems and air conditioner systems.

the electricity sector to provide a background to the emergence and growth of LSIC in electricity generation systems in Iran.

Based on World Bank classifications, Iran was an upper middle income developing country in 2009. Literacy rates increased from 50.8 percent in 1978 to around 87 percent in 2008, despite the fact that the population doubled over the same period. Official statistics in 2008 indicated that 26 percent of Iran's GDP was generated by the industrial sector, and this sector accounted for 17 percent of export revenues. The available data on Iran show that the share of high technology manufactured products within the total exports of manufactured products in 2007 was six percent. Throughout the nine decades since the start of the modernisation of the traditional economy of Iran in 1925, the government has always played a key role in industrialisation by supporting, directing and financing the process. The implementation of national development plans has been the main instrument of the government to enable the industrialisation process. Five such plans were implemented before the 1978 Revolution, and four more were undertaken subsequently.

The focus of policies shifted from the development of light consumer industries at the outset to more attention being given to heavier intermediate and capital goods industries in the later stages before the 1978 Revolution, a shift that continued after the Revolution. Progress was complemented with an expansion of local technological capabilities, which evolved from supporting the assembly of final products to developing the local chain of suppliers and building engineering and design capabilities. While the pre-Revolution plans pursued an import substitution strategy and focused largely on economic development, their post-Revolution counterparts added elements of export promotion with complementary objectives in the cultural and social aspects of development.

Within this broad context of industrialisation, the electricity sector in Iran appears to have developed from very limited coverage in Tehran in the 1900s to a strong position in terms of coverage, electricity generation capacity and depth of local capabilities in the latter stages of industrialisation. The electricity sector began with the dominance of private firms until 1965, when the generation, transmission and distribution of electricity were nationalised in response to the growing need for electricity for industrialisation. While the country suffered from severe power shortages during the eight-year war with Iraq in the 1980s, it started exporting electricity in the 1990s. The government embarked upon privatisation of the sector in the 2000s, attracting private investment into the development of new electricity generation plants. Currently, Iran is number one in the Middle East and West Asia and number 17 in the world in terms of electricity generation capacity, and more than 98 percent of its population has access to the grid, significantly higher than the average of 73 percent in developing economies. The following table provides a timeline of major developments in the Iranian electricity sector.

1885	First electricity generator was installed in Tehran's royal palace, three years after the world's first power plant was built in New York.
1904	Construction of the first commercial electricity generation and distribution system in Tehran.
1954	The first group of local engineers was sent abroad to learn technical and financial management of operations in the sector to replace foreign professionals.
1955-1962	Construction of the first parts of the transmission network.
1963-1967	Growth of electricity consumption arising from the industrialisation; nationalisation of electricity generation, transmission and distribution; emergence of private local firms for manufacturing equipment for distribution networks, and for managing distribution projects
1968-1977	Establishment of consulting firms in collaboration with leading international firms to serve local projects.
1978-1988	Revolution and start of the eight-year war with Iraq; establishment of a local research centre to meet the technological challenges emerging in the operation of the electricity network.
1989-1994	Development of local capabilities in manufacturing equipment for electricity generation and transmission projects and management of such projects.
1995-1999	Selling electricity to neighbouring countries; starting to export equipment and services to overseas projects; supporting private investments in electricity generation
2000-2009	Expanding the coverage of the electricity network; privatising the government's assets in the generation of electricity.

Table 2-1: A timeline of major developments in the electricity sector of Iran (Source: extracted from the text of this chapter).

Technological capabilities in the local electricity sector started with developing the knowledge and skills to operate the sector and progressed to supporting the manufacturing of equipment for distribution networks and managing distribution projects and feasibility studies for projects before the 1978 Revolution. While the pre-Revolution governments were more concerned with the overall development of the sector, the post-Revolution Ministry of Energy combined these objectives with the aim of developing local technological capabilities, expanding local capabilities into the manufacturing of equipment for transmission and generation of electricity, managing such projects and enhancing local capabilities for research into the operation of the sector. Iran currently relies heavily on its local capabilities for developing the electricity sector. Iranian firms have also started to export their products and services to overseas markets. Within the context of the development of local capabilities, Farab and Mapna were established in the early 1990s as prime contractors for local hydro and thermal electricity generation projects. These firms were expected to realise the potential of local suppliers in projects, which had been neglected in the past. Both firms appear to have developed some capabilities for systems integration in local projects and have started exporting their services and products to overseas markets, suggesting the need to explore this in depth in the detailed research of this thesis.

The review of developments in this chapter suggests that it is useful to focus on the evolution of capabilities in a dynamic setting. It also suggests a range of issues for further research, centred on the types of capabilities that appear to have emerged in the Iranian context, whether any sophisticated capabilities for designing the systems have been involved, and the advantages and limitations of such capabilities. Furthermore, it is intriguing to assess how far local capabilities have advanced and whether local firms are still dependent on hiring foreign engineers to carry out projects. By assessing these kinds of questions, this thesis hopes to show how local capabilities in Iran have been built, and to reveal the extent of progress in LSIC. The following chapter reviews the current literature to examine its potential contributions to understanding the evolution of LSIC in Iran's electricity sector.

3. Chapter Three: Literature Review

This research aims to understand the nature and evolution of latecomer systems integration capability (LSIC) in Iran's hydro and thermal electricity generation systems. This industry demonstrates the characteristics of the high-value high-technology capital goods sector, sometimes referred to as CoPS in innovation studies. The theoretical and empirical literature relevant to this research includes that dealing with systems integration in CoPS, the literature on capability in developed countries and the latecomer firm literature. These bodies of literature are, however, largely disconnected and only offer partial perspectives on the issues of LSIC. Therefore, this chapter examines the relevant aspects with the intention of identifying the elements that might contribute to building a conceptual framework for this study.

The literature concerning systems integration in CoPS is investigated in order to understand systems integration capability in a 'leadership' context and to assess its limitations for the case of LSIC in Iran, an industrialising country. The review of capability theory in developed countries is focused on how capability is conceptualised, and on identifying the issues relevant to empirical research into capability evolution. The literature on building technological capabilities in latecomer contexts is also reviewed in order to examine the extent to which this might help explain the nature and evolution of LSIC in Iran.

This chapter is organised in four parts. The first section combines various elements of the CoPS literature to illustrate the strategic importance of systems integration capability and to delineate its constituent parts. Its implications for this thesis are also discussed. The second section investigates what turn out to be problematic definitions in the literature on capability evolution in economically developed countries. It also illustrates the implications of existing research for the issues of LSIC. The third section shows how the evolution of technological capabilities is empirically examined in latecomer contexts, and discusses how these findings might help to understand the Iranian case. The final part provides the conclusions.

3.1 Systems integration in CoPS

The subject matter of this research is systems integration in the business of designing, engineering and constructing electricity power plants. This business demonstrates the characteristics of complex products and systems or CoPS (Hobday 1998). It is difficult to provide an accurate figure for the costs of a power plant project, as the costs of each project depend on the characteristics of the location, the output power of the plant, the type of technology involved and the forces of competition, among other factors. Roughly speaking, a 250MWs hydro power plant cost around US$62m in 2010 (excluding dam construction), of which more than $20m is spent on the design, engineering and development of core systems, namely the hydro turbine and the generator. Similarly, a typical 236MWs gas turbine power plant cost around $110m in 2010, of which $40m is spent on core systems, namely the gas turbine and the generator (Iranian Authorities for Power Generation Development, 2010). These rough numbers fall within the defining threshold of CoPS as suggested by Acha, Davies et al. (2004). Furthermore, power plants are built on a project basis and plant systems often need high amounts of project-specific customisation, which means we can safely classify these types of power plants as CoPS. Some of the core systems of a power plant, such as the turbine and the generator, can also be classified as CoPS according to the above conditions. This section explores the literature on strategies, capabilities and innovative activities of 'leadership' CoPS suppliers to examine its potential contribution to understanding the nature and evolution of latecomer systems integration capabilities.

Projects are used as a method of organising industrial activity across firm boundaries in a range of high-technology industries (Hobday, Davies et al. 2005). Systems integration as a capability underpins the organisation of production and innovation in this context. While systems integration is therefore important to a wide range of high-technology sectors, CoPS industries are traditional domains of systems integration (Hobday, Davies et al. 2005).

Within the innovation studies literature, a distinction has been made between mass-produced consumer goods, low-technology capital goods and high-technology, high-value capital goods. The latter are sometimes known as Complex [1] Product Systems or CoPS (Hobday 1998). CoPS are defined as high-cost, engineering- and software-intensive goods, systems, networks, infrastructure, engineering constructs and services (Davies and Hobday 2005). Dams, intelligent buildings, aircrafts, locomotives and power plants are some examples of CoPS. Many CoPS[2] are at the core of industrial growth and the modern economy. From 1997 to 1999, CoPS represented 19 percent of total gross value added in the production and construction industries in the UK, amounting to around 21 percent of total employment in the above industries (Acha, Davies et al. 2004).

A body of literature has developed around innovation in CoPS (see for example Prencipe, Davies et al. 2003; Davies and Hobday 2005). The core idea behind research in this area is that CoPS industries have characteristics that distinguish them from mass-production, and which can affect the features of innovation and industrial organisation in this sector. The elaborate hierarchy of systems in CoPS, and the number of organisations involved in the production process put systems integration at the centre of the tasks that leading suppliers of CoPS perform. As Figure 3-1 shows, the customer often sits at the top of the hierarchy, and the prime contractor or leading systems integrator is responsible for the integration of disparate technologies, relevant knowledge-bases, large-scale project management and coordination of a network of business partners to deliver the output.

[1] The notion of complexity might refer to the number of customised components, the breadth and depth of knowledge and skills required, the degree of new knowledge involved in production, the degree of customisation of the final system, the number of actors involved in the process and the number of possible architecture and component design paths (Hobday 1998).

[2] Acha, Davies et al. (2004) describe a method to identify and classify CoPS based on two sets of tests: first and second-tier CoPS tests.

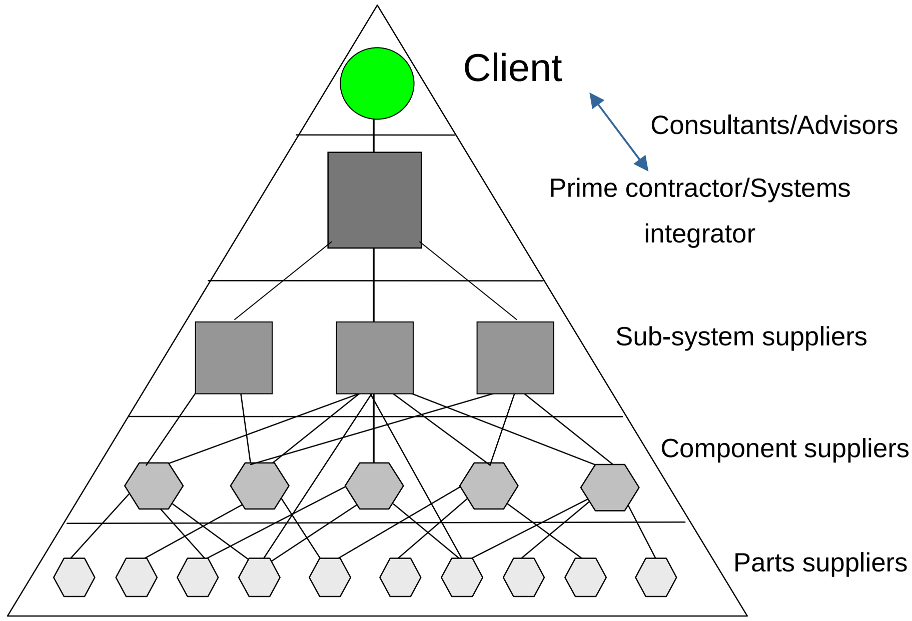


Figure 3-1: Integration of systems, adapted from Davies and Hobday (2005).

Sapolsky (2003) describes how systems integration processes were developed in the USA in a quest for coordination in building new complex technologies and industries for military purposes during the Cold War. Military systems at this time were becoming increasingly complex, requiring the involvement of various disciplines, a trend that seriously challenged the traditional single-discipline, linear approaches of system development. It became necessary that project teams integrate diverse disciplines, and there was a need for new organisations and skills to manage the design and development of complex systems.

During the Second World War and the Cold War, systems integration ideas and structures grew primarily as a technical field. Faced with the challenges of large-scale military technologies such as the atomic bomb, satellites and ballistic missiles, scientists, engineers and managers developed their own new techniques to cope with the diversity and scale of information and technology (Johnson 1997). Scientists created operations research, engineers developed systems engineering, and managers created project management techniques, each technique playing a distinct role in the development of procedures for military R&D. Systems engineering (including systems integration) was a technical field, emphasising meeting the technical specifications of the system. Gradually in the 1960s DoD and NASA further developed the ideas of the above three systems approaches into coherent bureaucratic processes, resulting in the widespread use of systems integration. Today, major suppliers of military systems see their primary task as systems integration and call themselves prime contractors, although, in some cases, systems integration tasks may be outsourced to specialised suppliers by the prime contractor.

In current practice, systems integration has become more complex, and no single organisation can claim to carry out this task alone. As an example, Gholz (2003) identifies three levels of systems integration, each being carried out by a group of specific organisations, in the modern US military sector. For the prime contractors (e.g. BAE or Lockheed Martin), systems integration is the ability to generate the conceptual design, control the supplier network, and deliver the final system according to its specifications. Sub-contractors, in turn, possess skills in engineering and production of components or sub-systems. Non-profit technical advisors (e.g. university research centres), specialist government laboratories, and organisations that manage weapons acquisition (e.g. the Department of Defense), as well as the military users of the weapons (e.g. the Army or Navy) are concerned with the definition of the system, its application in operations, feasibility studies and trade-offs therein.

These different systems integration roles often require different capabilities. For acquisition planners that award contracts (e.g. the Department of Defense), systems integration is the expertise to set the initial technical requirements of the system and evaluate bids from competing prime contractors. For military 'user' organisations (e.g. the Army or Navy), systems integration is the skill to understand the capabilities and limitations of the weapons platforms, and to predict the use of the system in an operational environment.

	Component systems integration	**Platform systems integration**	**Architecture systems integration**
Distinguishing skills	Technical capabilities in specific core areas	Project/subcontractor management	System definition
Key tasks	Engineering, development, component production	Production, systems assembly	Trade-off studies, customer interface
Organisations	Subcontractors such as Northrop Gumman Electronic Systems	Prime contractors such as Lockheed Martin Aeronautics	Technical advisors such as MITRE and SAIC

Table 3-1: Levels of systems integration capability in the US defence industry (Gholz 2003)

The advantages of the systems integration approach quickly spread beyond the military to other complex system industries from the 1950s. In many industries, systems integrators have taken a stronger role in leading the innovation process and coordinating networks of internal and external suppliers. As an activity, systems integration has two faces. The first face concerns internal activities in sourcing and integrating the inputs needed for producing outputs. The second face, which has become more important in recent years, refers to the external activities of firms as they integrate components, skills and knowledge from other organisations to produce ever more complex products and services (Hobday, Davies et al. 2005). As the evidence shows, both faces of systems integration are strategic in nature, going beyond the boundaries of the three approaches to big technologies to become vital to the competitive advantage of prime contractors such as GE, BAE and Boeing. In particular, systems integration, as a capability, has become one of the strategic capabilities of CoPS suppliers in the sense that it underpins the positions they can occupy within the value chain of the industry (Hobday, Davies et al. 2005).

Systems integration is also important to the productivity of CoPS suppliers. It is the primary capability by which leading suppliers manage the twin processes of vertical integration and disintegration to cope with the dynamics of the product and the environment. It is among the key factors that enable firms to choose where and when to move upward or downward in the value chain. Systems integration is no longer a primarily technical task. Instead, it is also concerned with the division of production and innovation tasks across the value chain of the industry, the organisation of major CoPS projects, and the choice of business partners and decisions on what to source internally and externally, directly influencing how a firm competes, with whom it collaborates and with whom it competes.

Because of the differences between CoPS and mass-produced goods, in particular the wider opportunities for customisation for each client, the scope of integrating high-value services into each CoPS product is greater than in the case of most other products. Furthermore, customers are increasingly demanding complex solutions composed of technologies, products and specialised services, which sometimes need to be sourced from other suppliers. Suppliers of CoPS therefore are increasingly adopting 'integrated solutions' strategies, no matter whether their base is in manufacturing or in services. This strategy utilises systems integration capabilities to integrate a range of services such as consultancies, operations, maintenance and finance into their offerings, thereby creating competitive advantages in the market (Davies 2004; Davies, Brady et al. 2007). The evidence shows that although systems integration is the core capability in this regard, additional sets of service capabilities such as finance, business consultancy and system operations are required for the successful provision of integrated solutions.[3]

In a broad sense, systems integration can be defined as the capabilities that allow firms, government agencies, regulators and a range of other actors to define and combine together all the necessary inputs for a system, and agree upon a path of future systems development. Narrowing this to the context of producing CoPS, systems integration can

[3] Davies et al (2007) identify two typical approaches of organisations in providing integrated solutions: (1) the vertically integrated systems seller that produces all the products and services required; and (2) the systems integrator that relies on components and services supplied by others. The evidence shows that firms in practice often combine elements of both.

be defined as the core technical and strategic capabilities that enable a CoPS supplier to combine all the various production inputs, including components, subsystems, software, skills and knowledge, to produce a product, system, construct, network or service (Hobday, Davies et al. 2005).

In a case study of the aircraft engine control industry, Prencipe (2000) shows how engine manufacturers adjust their technological capabilities over time. Prencipe shows that engine manufacturers retain a deep understanding of the technological capabilities of components, well beyond the production boundaries of merely assembling the engine, to specify, assess, test and integrate components produced externally. They also need to retain these technological capabilities to benefit from technological changes that happen at the level of components, presumably outside the firm. As such, systems integration comprises a wide set of technological skills. Prencipe (2003) indicates that the competitive focus of the aircraft engine control industry is on the skills required to understand the underlying bodies of knowledge and ensuing systems behaviour, rather than on the skills required for assembly, as illustrated in Table 3-2. It is therefore contended that the integration of the product is primarily the integration of technological knowledge rather than physical assembly.

Understanding of the underlying technological disciplines and therefore ability to integrate them
Technological understanding of the entire system's behaviour in terms of relevant parameters
Ability to design the entire system
Ability to design most key components of the system
Ability to assemble components' interfaces

Table 3-2: Underlying skills of systems integration in the aircraft engine control industry, in descending order in terms of competitive importance (Prencipe 2003)

However, systems integration is not just about technical aspects. It is also understood as a coordination mechanism, a distinctive capability of CoPS systems integrators to set up a network and lead it from an organisational and technological viewpoint (Prencipe 2003). Two analytical categories of systems integration capabilities can be identified: synchronic and diachronic. Synchronic systems integration refers to the capabilities required to sustain competitive advantage in the short term. It is composed of a range of in-house capabilities to set the product concept design, decompose it, orchestrate the work of several companies, and then recompose the product within an existing architecture. It comprises technological skills and experience to coordinate the development of a new product within a predefined time period and financial budget. It also includes technological capabilities to exploit the potential of existing product architecture to develop new product versions to cater to customer requirements. Within a product family, firms introduce incremental and radical technological innovations at the component level to adapt and improve upon the performance of the existing architecture. Thus, from a technical perspective, synchronic systems integration is primarily comprised of systems engineering skills. From an organisational perspective, however, synchronic systems integration refers to the capabilities required to manage inter-organisational communication processes and to coordinate the interactions among project partners to realise the project on time, within budget and to specifications. This aspect of systems integration capability is what is primarily and commonly known as project management practices (PMBOK, 2003).

Diachronic systems integration,[4] in contrast, refers to the capabilities underpinning long-term competitiveness, allowing firms to keep pace with technological developments. It refers to the capabilities required to envisage and move progressively towards different and alternative paths of product architecture to interpret clients' needs, and to coordinate change across technological fields and organisational boundaries. It comprises a spectrum of capabilities ranging from introducing incremental architectural innovations to introducing fundamentally new product architectures. In this respect, it is a capability allowing high-risk activities for exploring alternative paths of product configurations, and coordinating the development of new and emerging bodies of technological knowledge. Therefore, management of a firm's links to external sources of knowledge, such as universities and suppliers, becomes a critical part of its diachronic systems integration capability.

In addition to the above aspects of systems integration capability, the typical production process of CoPS requires that suppliers often participate in competitions to secure projects. They also need to provide services during the operation of the system if the contract requires this. The life-cycle of a typical CoPS project could be analytically divided into several phases: pre-bid, bid, project and post-project activities.[5] Pre-bid and bid phases include activities to engage with the customer and prepare proposals for bids or offers for strategic partners. The project phase consists of activities to set up a project organisation, undertake the project and hand over the system to the client. The post-project phase includes arranging the provision of operational, maintenance and ongoing support services. The skills and experience enabling the conduct of these typical phases are broadly categorised as project capabilities in CoPS (Davies and Brady 2000). It is argued that functional efficiency gained by producing higher levels of output in mass-

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[4] In practice, it may have overlaps with the previous category.

[5] Davies and Hobday (2005) argue that pre-bid is an important part of the project life-cycle since the effective management of the front end of a project leads to better performance during the later stages. They believe that managers should enter high-level pre-bid negotiations with the customers to understand their needs before an invitation to tender has been issued.

manufacturing industries is not the main source of cost reduction in CoPS. However, effective bid and project management capabilities to win more bids, with lower preparation costs or shorter preparation time, and to ensure their successful completion could be sources of efficient utilisation of resources in this industry (Davies and Brady 2000). In this sense, project capabilities, including but not limited to the project management capabilities discussed in synchronic systems integration, form an important part of systems integration capabilities.

As the evidence shows (Hobday, Davies et al. 2005), systems integration has evolved from a narrow technical origin in systems engineering to include new areas of functional skills, including services, project capabilities to manage risks and uncertainties, capabilities to learn from feedback generated during post-project activities, and strategic capabilities to move along the value chain of the industry. Figure 3-2 shows how this view of systems integration relates to wider discussions of organisational capabilities (Chandler 1990).

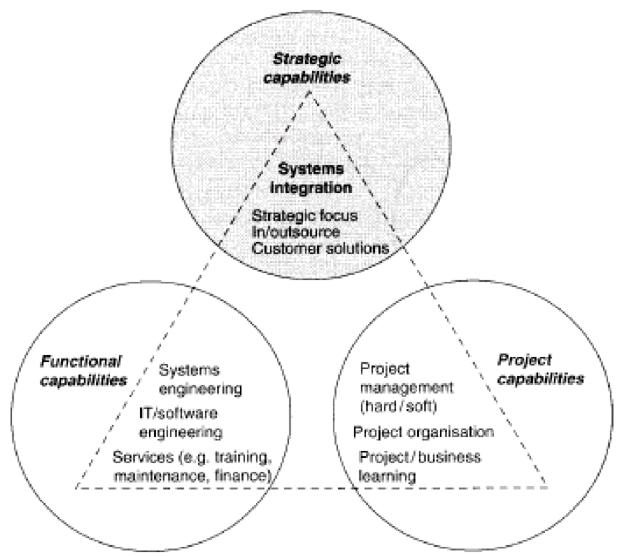

Figure 3-2: Systems integration and organisational capabilities (Davies and Hobday 2005)

Having explored the concept of systems integration capability in the literature, we now turn to the subject of how systems integration capabilities evolve at the firm level. It has been argued that the ability to utilise an existing knowledge-base to improve on operational effectiveness depends on the type of project tasks involved. A project is defined as unique or novel to differentiate it from volume-based routine operations. Nevertheless, firms often manage projects based on bid preparation and project management manuals, which normally correspond to routine operations. Although the output of a project is unique, project tasks can therefore be on a spectrum of unique to standard activities (Lundin and Soderholm 1995). Focusing on the project tasks, projects thus can be defined as unique, repetitive or hybrid.

Improvements based on learning by doing cannot be easily realised in unique tasks. In repetitive projects, however, there are opportunities for cumulative learning and efficiency gains. Contrary to the concepts of scale advantages and learning curves in high-volume, functional organisations, productivity improvements in lower-volume project activities are often based on reductions in the costs of bid and project activities, reductions in project delays and satisfying wider technical specifications.[6] Economies of repetition (Davies and Brady 2000) are obtained by performing a growing number of similar projects at lower costs and more effectively with regard to customer specifications. Firms develop specific organisational structures and procedures to capture learning and improve on activities. Economies of recombination (Grabher 2004) can be obtained by deploying the experience from previous projects to standardise product and service modules, thereby increasing efficiency through means such as reducing engineering activities and offering lower-cost customised solutions to each customer.

Suppliers of CoPS often expand into new lines of business by utilising what is known in the literature as 'base-moving' projects (Davies and Hobday 2005). It is suggested that the move into a new technology or market base usually starts with organising a first-of-its kind project and continues with learning at two interacting levels: (1) bottom-up, 'project-led' learning; and (2) top-down, 'business-led' learning (Davies and Brady 2000; Brady and Davies 2004). The evidence shows that firms consequently create new structures, implement new procedures, and select among the possible practices to prepare similar bids and perform similar projects more efficiently and effectively in the future.

Soderlund and Tell (2009) illustrate how elements of CoPS systems integration capabilities might evolve through time, in response to internal and external forces. The research breaks down the history of the power systems division of Asea Brown Boweri (ABB), a leading Swedish systems integrator, into four project epochs, indicating major changes in the nature and composition of capabilities. The first epoch was characterised by operations in the local market in close cooperation with the local state client. During this period, ABB accomplished large complex projects by gradually building its capabilities to organise such projects. However, the company not only deployed the engineering and managerial capabilities of its state client to undertake projects, but also collaborated with the client for research and development purposes. The second epoch was concerned with entering into international markets, leveraging project references in the local market. During this stage, the firm learned to work independently from its local client; however, it was still reliant on the technological and managerial capabilities of clients in its new markets,

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[6] Bids and projects are referred to as similar when the same sets of capabilities, routines and components are required for their execution (Davies and Hobday 2005; 76).

which were generally economically developed nations. In the third epoch, the firm expanded its markets to cover developing countries, often lacking clients with advanced technical and managerial capabilities to handle projects. As such, during this stage ABB developed a broader range of capabilities to deliver projects in a turn-key mode. New organisational structures were developed, project managers were expected to embody a wider range of skills in management and technology and the firm was integrated vertically across the value chain to provide various components and services for complex turn-key projects. During the last stage, up until 2003 when the study was carried out, ABB acquired capabilities to also finance turn-key projects in developing countries. The company developed relationships with the Swedish Export Credit Council and some financial institutions, and built its internal capabilities in financial engineering, risk management and business development. Although ABB was established and developed in a different type of economy, insights drawn from this research make it interesting to examine the role of local market and local state clients in the development of latecomer systems integration capability. It also gives some ideas for how to assess the evolution of latecomer capabilities in response to changes in the competitive environment.

3.1.1 Implications for research

In order to assess the potential contributions of this literature to understanding the nature and evolution of LSIC, it can be divided into two overlapping but still distinctive parts. One part of the literature largely focuses on understanding the nature of systems integration in the context of developed countries (Prencipe 2000; Prencipe 2003; Hobday, Davies et al. 2005) and its historical origins (Johnson 1997; Sapolsky 2003). The other part goes further to help understand the evolution of systems integration capabilities again in the context of economically developed countries (Davies and Brady 2000; Brady and Davies 2004; Davies 2004; Soderlund and Tell 2009).

The first part of the literature, detailed above, helps us understand the strategic importance of systems integration capability for leading suppliers of CoPS, and provides us with insights into the nature of systems integration capabilities and their evolution. Nonetheless, the content and context of the literature on their own are insufficient for developing the concept of LSIC in Iran. For instance, Prencipe (2003) breaks down systems integration capabilities into two overlapping categories of diachronic and synchronic systems integration capabilities to explain the (primarily) technological underpinnings of short-term and long-term competitiveness among leading suppliers of CoPS. These conceptualisations, however, appear unable to capture important innovative activities in the latecomer context which, compared to advancing innovation frontiers via R&D in developed economies, could be in areas such as improving the systems to fit the local conditions or even designing a system with a performance level lower than that of the technology frontier.

The second part of the literature, in terms of our classification, focuses on the evolution of systems integration capability. Soderlund and Tell (2009) provide us with insights into how latecomer systems integrators may leverage local experience to progress in overseas markets, and how the composition of capabilities may be affected by the evolution of the competitive context. However, the application to the Iranian context of some other findings in the literature raises conceptual challenges. While Davies (2004) describes the strategies of leading systems integrators to move across the value chain of the industry and to offer integrated solutions, he speaks less about how the required capabilities are developed. The proposed mechanisms of learning detailed by Davies (2004) and Davies, Brady et al. (2006) are unlikely to be applicable in the latecomer context in which firms presumably lack initial capabilities and operate in an unfavourable environment in terms of skilled resources. For instance, while a supplier of equipment for telecommunication networks in developed countries can obtain experienced human resources for the design of such networks from the labour market, previous experience in designing telecommunication networks might not exist in the latecomer context. Therefore, existing frameworks, concepts and insights need to be amended for the latecomer context, and must be assessed in the light of the actual evidence.

From a broader perspective, this thesis will extend the range of industries in empirical investigations of CoPS by adding cases of electricity generation projects from Iran, a developing economy. As the literature shows, the details of systems integration can differ from industry to industry, and can vary according to the nature of the system that is being integrated (Hobday, Davies et al. 2005). Therefore, investigating systems integration in the global context of electricity generation projects will hopefully clarify the boundaries of this research.

3.2 The subject of capabilities

In recent decades, a large body of literature has been produced on the nature and importance of firms' capabilities, within the strand of the resource-based view of competitive advantage in the strategic management literature (Penrose 1959; Rumelt 1984; Wernerfelt 1989; Barney 1991). At the time of writing this chapter, a narrow search on firm capability in three major online journal databases of business, management and economics[7] returned over 1500 peer reviewed papers from various subject areas such as

[7] The databases are ABI/INFORM Global (ProQuest), Business Source Premier (EBSCO) and JSTOR.

strategy, marketing, information technology and innovation studies. In spite of this breadth, however, the literature suffers from some conceptual ambiguities.

One aspect of the literature that still seems to be unsettled is the confusion over the definition of concepts. While most authors use ‘capability’ and ‘competency’ interchangeably (see for example Prahalad and Hamel 1990; Henderson and Cockburn 1994; Helfat and Peteraf 2003), Tunzelman (2009) argues that distinguishing the two helps enrich our understanding of how firms, regions and countries grow over time. He suggests 16 criteria to distinguish between the two concepts, emphasising that competencies include enhancements to resources, such as more educated labour or more advanced technologies, while capabilities go a step further and involve enhancements to services, i.e. the areas to which the resources are applied in the sense of Penrose (1959). In Tunzelman’s view, this distinction leads to the realisation that acquiring competencies, mostly embodied in human resources, is not enough for growth, and there should be complementary investments in capabilities. However, this definition implies that competencies are in the nature of resources.

Another inconsistency is the different ways in which relationship between the concepts of ‘capabilities’ and ‘resources’ is specified in the literature. Some scholars assume that resources include capabilities, recognising capabilities as a subset of resources (see for example Barney 1991; Foss 1999), while for a second group of authors the relationship is the other way around. Even in the latter group, some writers define capabilities so as to include a wide range of resources (see for example Henderson and Cockburn 1994; Levinthal and Myatt 1994; Bell and Pavitt 1995), while others specify capabilities as mere skills or knowledge sets (see for example Prahalad and Hamel 1990; Lall 1992). Among a third group of researchers, capabilities are distinguished from resources so that capability is a capacity of a group of resources, or a capacity to deploy resources, meaning that the mere assembly of resources would not result in the formation of capabilities (see for example Grant 1991; Amit and Schoemaker 1993; Teece and Pisano 1994; Helfat and Peteraf 2003).

In all the above cases, including the term ‘resources’ in the definition of capability complicates the statement unnecessarily, as it must be complemented by another statement in order to define resources. It only exacerbates the situation to realise that similar opposing views can be found in the case of resources (see for example Eisenhardt and Martin 2000; Grant 1991). The use of conflicting definitions, or, as some call them confusing and obscure definitions (Dosi, Nelson et al. 2001), hinders to some extent the ability to relate the contributions of some bodies of research to other bodies of existing literature (Priem and Butler 2001).[8]

The literature also contains some tautological definitions of capabilities (Williamson 1999; Dosi, Nelson et al. 2001; Priem and Butler 2001; Arend and Bromiley 2009; Barreto 2010). For instance, Helfat and Peteraf (2003, p999) define capability as follows:

> "A resource refers to an asset or input to production (tangible and intangible) that an organization owns, controls, or has access to on a semi-permanent basis. An organizational capability refers to the ability of an organization to perform a coordinated set of tasks, utilizing organizational resources, for the purpose of achieving a particular end result."

While this definition of resources and their separation from capabilities is debatable,[9] defining capability using 'ability', which appears to be synonymous with capability, does not help operationalise the concept for empirical research.

Putting the above points aside, different categories of capabilities can be identified in the literature. Most often, the general term of 'organisation capabilities' is used to refer to all kinds of capabilities in a firm, including technological capabilities. Scholars of innovation studies, however, often tend to focus more closely on technological capabilities or innovation capabilities, and recognise organisational elements such as linkages and organising as vital parts of these capabilities (see for example Bell and Pavitt 1995).

A distinction is generally made between operational capabilities and dynamic capabilities, so that the former enables firms to perform their ongoing tasks of making a living (Helfat, Finkelstein et al. 2007), while the latter concerns building, integrating or reconfiguring operational capabilities. Dynamic capabilities are the building blocks of a larger framework in the strategy literature to explain the sources of sustainable competitive advantage for firms, in particular those operating in fast-moving business environments (Teece 2007). Although the literature on dynamic capabilities suffers from similar tautological definitions as those detailed above, a relatively extensive literature[10] has developed around the nature of dynamic capabilities and how they affect firms' performance (Helfat 2000; Augier and

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[8] Another concept that often is used in the same confusing way is that of ''routines'. In the literature, routines are used interchangeably with activities and are often considered as constituent parts of capability. For instance, Dosi, Nelson et al. (2001) suggest that the term 'skills' be used at the individual level, and 'routines' at the organisational level. Accordingly, individual skills form building blocks of routines, and routines become building blocks of capabilities. Dosi, Nelson et al. define routines as units or chunks of organised activity with a repetitive character (p4). However, defining routines as a form of activities implies that capabilities are in turn a form of activities, while, in essence, capabilities are different from the activities they support.

[9] In addition to the previous discussion about different approaches to specifying relationships between resources and capabilities, this definition limits resources to inputs to production, excluding the variety of other assets that might indirectly support production.

[10] For an empirical example see Eisenhardt and Martin (2000).

Teece 2006; Helfat, Finkelstein et al. 2007).[11] For instance, Teece (2007) disaggregates dynamic capabilities into 'capacities' for sensing and shaping opportunities and threats, 'capacities' to seize opportunities, and 'capacities' to maintain competitiveness through enhancing, combining, protecting and reconfiguring assets. This account of dynamic capabilities closely resembles the traditional approaches of strategy formulation (see for example Ansoff 1965; Andrews 1971), somehow contradicting the original premise of dynamic capabilities (Teece and Pisano 1994). Nevertheless, the dynamic capabilities literature appears to be largely inapplicable to research into the nature and evolution of LSIC because latecomer systems integrators may not operate in a fast-moving, international competitive market, at least in their early stages of life. Furthermore, while the dynamic capabilities framework concerns firms that already have a competitive capability basis, latecomer firms by definition lack such a basis and are in contrast focused on building initial capabilities for competitiveness. As such, latecomer firms are less concerned with combining and reconfiguring assets in the sense of the dynamic capabilities framework.

Despite some unclear definitions and the existence of various classes of capabilities, the literature offers a relatively rich account of the micro elements underlying capabilities.[12] Leonard-Barton (1992) suggests that skills and knowledge bases (embodied in people or disembodied in the form of technical systems) are at the core of capabilities, but certain organisational dimensions affect this core. These dimensions include managerial systems (such as formal and informal ways of creating knowledge), organisational norms and values assigned to various types of knowledge (such as engineering versus marketing expertise) and processes of knowledge creation and control (such as formal degrees versus experience). The empirical research of Eisenhardt and Martin (2000) points to teams and routines or processes as other micro elements underlying capabilities. The range of micro elements is in fact broader than merely organisational and technical elements, and includes important personal characteristics of individuals, especially managers (Augier and Teece 2006; Teece 2007). It is suggested that leadership qualities, entrepreneurship, insights and judgment play a focal role in enabling firms to sense and analyse drivers of change, and to respond through reconfiguring existing assets.

3.2.1 Evolution of capabilities

Although research into the evolution of capabilities has developed momentum later when compared to other issues of capability theory, it offers some insightful contributions

[11] Priem and Butler (2001)'s criticisms of the definition and operationalisation of dependent variables (competitive advantage) and independent variables (capabilities) in RBV research are also applicable to the case of the dynamic capabilities framework.
[12] Authors have used other terms instead of elements. For instance, Teece (2007) uses 'microfoundations'.

relevant to this thesis. Winter (2000) proposes a conceptual account of when firms might stop making further investments in acquiring and learning capabilities. He defines overt learning as efforts marked by observable allocation of attention and resources to the task of acquiring the capability. To answer the question of when firms might stop overt learning, Winter proposes a model based on the 'satisficing principle'. According to the model, overt learning efforts are undertaken when a perceived need for improvement exists in the organisation, normally arising from dissatisfaction with the current ways of doing things. The overt learning is supposed to stop when the expected improvements in the performance of the related activity are realised. Winter refers to this performance goal as the 'aspiration level'. Various internal (to the firm) and external factors determine the aspiration level, including guidelines or pathways suggested by technology suppliers, the strategic objectives of the firm, the previous experience of the firm, the experience of other firms, the aspirations of managers, and the limitations imposed by the costs of learning. The aspiration level, however, is likely to be adjusted as the outputs of learning activities emerge. Although the overt learning stops after a certain period, it may be reignited some time later in response to changes in the competitive situation or as a result of continuous improvement initiatives within the firm.

As such, Winter argues that capability is contextual. Changes in the competitive situation combined with the learning response to those changes form the key drivers of long-term changes in capabilities. Heterogeneity in aspiration levels and differences in the effectiveness of learning mechanisms are therefore suggested to explain heterogeneity in firms' capabilities. Winter provides an interesting conclusion:

> "The above discussion identifies a number of plausible influences on this decision [stopping overt learning] that are not grounded in the specific reality of the learning effort but rather reflect contextual factors... Thus, there are sources of heterogeneity in achieved performance levels that have little to do with the technical difficulty of raising the capabilities to a higher level."
> (Winter 2000, p991)

While Winter (2000) provides very useful insights into the evolution of capabilities, he speaks less about the learning process itself and how the aspiration level and overt learning efforts for one capability could affect developments of other capabilities in a firm.

Helfat and Peteraf (2003) provide a general framework claiming to explain the emergence and development of capabilities. They also try to explain the heterogeneity of capabilities among firms. For these purposes, they present a capability life-cycle model, consisting of four main stages, namely founding, development, maturity and transformation, in which the transformation stage itself contains six branching possibilities. The model assumes that capabilities reside within a team, and in order for a capability to start its life there should be a team or group, leadership and a central objective. The founding team supposedly brings in some endowments, including the human capital (knowledge and experience), social capital (internal and external ties) and cognition of its people. Teams with the same central objective, therefore, may follow different paths of capability evolution due to differences in their initial endowments. As the capability develops over time, it reaches the maturity stage, in which exercising the capability causes it to become more embedded in the 'memory' structure of the organisation. In this context, how well the capability is maintained depends on how often and how consistently the team exercises the capability. The emergence of powerful internal or external forces, however, may alter the trajectory of capability, starting the transformation stage. Managerial decisions are key internal factors in shaping the processes of the transformation stage. Some external forces can also affect these processes, including changes in demand, technology, markets of raw materials and government policy.

In addition to some problems with the definition of capabilities in this model,[13] Helfat and Peteraf claim to have developed a model to explain the emergence and development of virtually '"any type of capability'' in ''any type of organization'', while the literature suggests that capabilities are contextual to the firm and the market (Winter 2000; Ethiraj, Kale et al. 2005). The conceptual framework also seems somewhat deterministic in depicting a specific direction for evolution, ignoring many contingencies that can prevent a capability from passing from one stage to another, such as the demise of leadership or adverse economic conditions that can scale down operations or shut down a firm before the capability reaches its maturity. Despite these conceptual challenges, this model provides us with helpful insights into the evolution of capabilities, such as its emphasis on the initial attributes of the founding group, which needs to be examined in the latecomer context.

In addition to conceptual contributions mentioned above, the empirical literature on capabilities[14] reveals the variety of research methods that are in use, indicates the factors

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[13] The issues of tautology and confusion between the concepts of capabilities and resources are discussed in the previous parts of this section. Some other problems also exist in their definition. Working in a reliable manner is defined as main condition for something to be called a capability, implying that initial attempts or initial successes do not indicate a capability. However, it is arguable that when a project firm does something in one project it holds the capability to do it whereas repeating it in the future is mostly a case of retaining the capability. Furthermore, this definition is unlikely to help empirical research. For instance, the authors argue that Toyota manufactures better cars (p999) so has a better manufacturing capability. This broad conception does not consider contextual elements that specify what types of cars, when and for what markets.

[14] A major part of this literature focuses on investigating the relationship between capabilities and competitive performance, testing the propositions of resource-based views of competitive advantage. In addition to the difficulties of measuring the independent variables, poor definitions of measures of the dependent variable (i.e. performance) and insufficient attention to controlling for factors other than capabilities that might affect the performance form the main challenges of these studies. This chapter focuses on how capabilities are operationalised in the literature, as other issues fall beyond the scope of this research. An assessment of these other aspects, including robustness of findings, can be found in Newbert (2007).

that might affect the evolution of capabilities and sheds light on mechanisms for building capabilities in the context of economically developed countries. Three groups of methods can be identified in empirical research into capabilities. One group of studies uses single or multiple quantitative indicators to measure capabilities (see for example Silverman 1999; Mansfield, Teece et al. 1979; Patel and Pavitt 1997). For instance, Ethiraj, Kale et al. (2005) use three metrics to measure project management capability in the software industry: number of in-process defects, effort overrun (person-month) and the extent of schedule slippage. The second group combines quantitative variables with qualitative measures of capabilities. For instance, Henderson (1994) combines the quantitative measures of R&D inputs and R&D outputs with qualitative measures of processes, structures and knowledge to measure research capabilities in the pharmaceutical industry. The third strand uses history-friendly case studies to investigate the variety of factors that shape capabilities, providing a descriptive account of how capabilities have changed through time e.g. (see for example Raff 2000; Rosenbloom 2000).

The studies that merely use measures of inputs to the capability building process, such as investments in R&D, cannot explain the resulting changes or outputs of the process. Similarly, studies that only use measures of output, such as patents, could be criticised for not exploring the 'black box' of capability building, ignoring its dynamics. Furthermore, each single variable can only illuminate some aspects of capability. Since researchers are unlikely to find one proxy or variable that reflects unobservable capabilities, it is more rigorous for quantitative studies to use multiple measures and explain how these multiple measures relate to the construct (Armstrong and Shimizu 2007). Another precaution with regard to quantitative measures is that firms might be reluctant to provide information on the measures that they consider competitively vital. For instance, Ethiraj, Kale et al. (2005) report this challenge in acquiring information on the performance of projects. Nevertheless, the focus only on inputs and outputs can result in losing sight of the actual learning process in building capabilities and the factors that affect it, while the literature suggests that heterogeneity of learning efforts is one factor explaining heterogeneity of capabilities. Capabilities are not merely the result of the tacit accumulation of experience, embedded in routines and learning-by-doing (Eisenhardt and Martin 2000; Ethiraj, Kale et al. 2005). They can also be the result of investments the firms deliberately make in building the micro elements that underlie capabilities. For instance, Zollo and Winter (2002) suggest that knowledge transformation processes, including knowledge articulation and knowledge codification processes, form a part of learning mechanisms.

The empirical literature provides us with other helpful insights into the evolution of capabilities which need to be amended and assessed in the latecomer context. Levinthal and Myatt (1994) present an integrated framework of firm-level factors (e.g. social capital), product market dynamics and managerial choices about markets and areas of specialisation to explain the evolution of capabilities. Leading customers and challenging markets are argued to create opportunities for learning new capabilities. Thus it is interesting to see how latecomer firms develop capabilities in the absence of leading customers, and to see in what stages of their lives they start interacting with advanced customers, and how these interactions affect the evolution of LSIC. Furthermore, a number of studies (such as Raff 2000; Rosenbloom 2000) indicate the important role of leadership qualities and the expertise and vision of managers in creating a heterogeneous stock of capabilities among firms. These insights need to be considered in building the conceptual framework for this research.

3.2.2 Implications for research

As discussed above, some definitions in the literature on capability development are tautological and confusing, impeding empirical research in this area and hindering the overall progress of the literature. Accordingly, attention needs to be paid to developing a clear definition of capability to support empirical research in this thesis. The potential contributions of capability theory to research into the nature and evolution of LSIC are discussed in detail above.

To recapitulate its main insights, the literature suggests that capabilities are contextual and specific to the firm and the market. It also contends that micro elements underlying capabilities can constitute personal characteristics of managers and people, such as their leadership and entrepreneurial qualities, in addition to common technological and organisational elements. The literature also provides us with valuable insights into the evolution of capabilities and factors that determine the heterogeneity of capabilities among firms. Therefore, for example, we expect that differences in the backgrounds and entrepreneurial qualities of founding teams are an important factor behind the heterogeneity of capabilities among firms. Similarly, the aspiration level governing the capability building efforts and the effectiveness of ensuing learning mechanisms are also expected to explain the heterogeneity. A variety of internal and external forces may affect the latter two factors. These insights and concepts need to be assessed with respect to the actual evidence in the latecomer context.

The existing frameworks for the evolution of capabilities sometimes suggest a rather deterministic direction for the development of capabilities, while capabilities in the latecomer context, and probably in developed economies as well, may remain dormant for a period of time or even degrade over time if, for instance, the firm fails to invest enough in its capabilities. This is more likely in a project business if, for example, the number of successful bids in a specific business area decreases, or if organisational arrangements fail to retain their capability after finishing a project. Research into the evolution of latecomer capability therefore requires a broad conceptual framework to capture these complex patterns.

Analysis of the empirical literature on capability reveals that an exclusive focus on measures of inputs into the capability building process comes at the cost of neglecting the outputs of the process. Similarly, a disproportionate focus on output measures means treating the capability building process as a 'black box'. An integrated approach containing measures related to inputs, outputs and learning mechanisms therefore would be useful for capturing the evolution of capabilities.

3.3 Latecomer firm theories

The resource-based theory (or view) of competitive advantage (Barney 1991; Grant 1991) in the strategic management literature is largely concerned with maintaining, nurturing and renewing capabilities by innovative firms in advanced countries. This literature analyses firms that have already accumulated a significant base of knowledge. However, latecomer firms lack such an initial base, and this fact has led to several studies in developing countries to explore the phenomenon of building capabilities in such disadvantaged firms. The latecomer firm theory, or catch-up studies at the firm level builds on the shoulders of the resource-based view (RBV), and amends it to encompass the issues and characteristics of firms in developing economies.

The history of catch-up can be traced back to earlier times when the US and European countries caught up with UK; Japan then bridged the gap between it and Western countries, and since then the process has taken place in the developing countries of South America, Asia and the Middle East over more recent decades (Nelson 2004). The phenomenon of catch-up has long been studied in the literature of economics, management and innovation studies, at various levels of analysis, namely micro, macro and meso levels (Gerschenkron 1962; Abramovitz 1986). One can produce pages containing names of references on catch-up. This section, however, focuses on firm-level studies of technological catch-up for the research purposes of this thesis. A brief review of related contributions in economics literature helps to understand the logic behind the development of this literature.

The 'convergence hypothesis' of neoclassical economics, based on Solow's growth model (Solow 1956), argues that economic growth mostly comes from exogenous technological progress. Since technology is exogenously supplied and freely available to all firms, all countries will eventually make use of new technologies and thereby catch up. The fact that many countries were not converging, Africa was 'falling behind' and Latin American countries were experiencing difficulties in catching up led to reassessments of the neoclassical theories in the 1970s. 'New trade' theories, such as that of Krugman (1979) put forward the idea that new products are invented and commercialised in the North (developed countries) and, after a delay, are copied in the countries of the South. Because of lower labour costs, Southern products out-compete similar products from Northern countries. This leads to the pressure on the North to introduce newer products, and a 'Schumpeterian' race between innovation (in the North) and imitation (in the South) arises.

As such, research on technology management in the latecomer context has traditionally assumed that innovation happens in developed countries, and developing countries have the option to select, acquire and use the imported technology, ideally improving upon it to fit local conditions. The term 'technology transfer' has been, therefore, widespread in the literature (see for example Enos 1989). However, as the progress of research in developed countries came to emphasise the 'stickiness' characteristics of technological knowledge, including tacitness and cumulativeness, even the use of an imported technology appeared to require indigenous technological efforts, causing a shift in the focus of catch-up studies towards the accumulation of technological capabilities, rather than the passive idea of technology transfer during industrialisation process.

In the early 1980s a network of Latin American scholars in the Research Programme in Science and Technology of IDB/ECLA investigated technical change and innovation across a number of manufacturing sectors in six Latin American countries (Katz 1984). The study showed that many firms adapted and improved the technologies they acquired from foreign suppliers, undertaking technological search activities with the purpose of generating incremental units of technical knowledge. Three categories of engineering and technical activities were identified that underpin indigenous generation of knowledge: product design engineering, process engineering, and industrial engineering or production planning. It has been suggested that latecomer manufacturing firms develop technological capabilities gradually, proceeding in a stepwise manner from relatively lower-risk areas to ones that are more complex and have longer-term effects. Firms, however, may follow distinctive sequences in capability accumulation depending on firm-specific factors such as ownership structure and production technology, and also depending on wider contextual elements such as the macroeconomic policies of the government.

The findings reported by Dahlman and Westphal (1982) and Dahlman, Ross-Larsen et al. (1987)[15] cover a number of firm-level studies about technological capability accumulation across four developing countries.[16] Technology is conceptualised as a collection of physical processes that transform inputs into outputs, the specifications of inputs and the outputs, and the social arrangements that structure the activities involved in carrying out these transformations. Technology is therefore the practical application of knowledge and skills to the establishment, operation, improvement and expansion of facilities for such transformations, and to the designing and improving of outputs. Technological capability is thus defined as the ability to make effective use of technological knowledge, subdivided into three functional areas: production, investment and innovation.

Within this broad definition, production capability is defined as the ability to adapt operations to changing market circumstances. Investment capability, however, concerns the performance of projects that are undertaken to develop the plant capacity, covering issues such as project costs and tailoring technological specifications for each project. Innovation capability, in contrast, is defined as the ability to develop production technologies that are less costly and more effective. The path of catch-up in technology is suggested to begin with simple, technology-deploying production capabilities, continuing through investment capabilities and finally to advanced innovation capabilities. Similar conceptualisations of latecomer technological (industrialisation) capabilities were later used by other researchers (such as Amsden 2001).

While the previous conceptualisations delineate various functional areas in technological capabilities, Lall (1992) extends the literature by defining levels of complexity or depth for each functional area in terms of basic, intermediate and advanced levels, providing a wider framework for capturing the evolution of latecomer technological capabilities.[17] In addition to this modification, Lall (1992) highlights the role of organisational elements in the composition of technological capabilities by adding a new functional area to the concept of technological capabilities: linkages within the economy. Linkage capabilities are defined as the skills needed to transmit information, skills and technology to, and receive them from, suppliers or other external actors. This framework proposes that although the nature of technological learning would indicate that mastery proceeds from simpler to more complex activities, each firm and type of technology may follow a distinctive path.

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[15] The findings are based on the research project 'The Acquisition of Technological Capability', financed by the World Bank.
[16] The countries are India, South Korea, Brazil and Mexico.
[17] The focus is on technological capabilities in industrialised production. These capabilities are defined within the life-cycle of an 'industrial venture' as: pre-investment, project execution, process engineering, product engineering, industrial engineering and linkages within the economy.

Lall (1992) suggests that the process of technological capability building at the firm level is derived from the forces of demand for change in capabilities and the potential of firms to build capabilities, a supply and demand dynamic. This dynamic is affected not only by internal factors such as the scale of production, but also by a variety of external factors such as developments in technology, and a range of factors in the national context such as national capabilities (such as skills created by formal training), incentives (such as inward-oriented versus export-oriented policies) and institutions (such as property rights). The sequence of accumulating different areas of technological capabilities is suggested to be the outcome of a firm's investments in response to these external and internal stimuli. This loose framework has since been deployed in the literature to describe the impacts of external factors on the evolution of technological capabilities (see for example Figueiredo 2008).

Similarly, Bell and Pavitt (1995) argue that dynamic efficiency does not follow automatically from the acquisition of foreign machinery, embodying new technology, and the accumulation of related operating know-how. Rather, it depends heavily on domestic capabilities to generate and manage change in the technologies used in production. These capabilities are based largely on specialised resources (such as a highly-skilled labour force) that need to be accumulated through deliberate investments. Compared to Lall (1992), Bell and Pavitt distinguish between two elements of industrial technological capabilities: production capability and technological capability.[18] Production capability is defined as the resources used to produce industrial goods at given levels of efficiency and given input combinations. These resources include equipments that embody technology, operational and managerial know-how and experience, product and input specifications, and organisational methods and systems. In contrast, technological capabilities are resources, including knowledge, skills, structures and linkages, needed to generate and manage technical change, change in forms such as introducing technology related to new products or plants, and incremental improvements in existing production capabilities. The latter set of resources often differs substantially from those required to operate existing technical systems. The behaviour of firms in accumulating technological capabilities is alleged to be impacted by factors such as market signals, government policies and management judgment.

The staircase model of technological capabilities, comprising two dimensions of function and depth, as suggested by Lall and Bell and Pavitt, forms the basis for a fairly extensive

[18] Production capability in their definition refers to the first step in the capability building process and includes elements from all six of the functional areas in the framework. Bell and Pavitt (1995) also extend Lall (1992)'s framework by adding 'capital goods supply' as a new functional area. However, the specific division of specialisation in an industry determines whether a firm itself deals with this function or whether it is undertaken by specialised suppliers.

empirical literature on latecomer technological capabilities (see for example Ariffin 2000; Dutrénit 2000; Figueiredo 2001; Tacla and Figueiredo 2006).[19] In this literature, the accumulation of a particular level of capability is often identified as when a firm becomes able of performing an activity that it had not been able to do before. Ariffin and Figueiredo (2006) extend the model by incorporating changes in the value of products. In other words, the evolution of technological capability can be understood as moving from routine production capabilities to complex innovation capabilities, in parallel with a progressive move towards higher-value products.[20]

An alternative way to assess technological capabilities in the latecomer context is developed by Bessant, Rush et al. (2001) and later used by Hobday, Rush et al. (2004). It is a framework for assessing firm-level technological capabilities based on (1) the degree of the firm's awareness of technological issues; and (2) how well the firm is prepared and is able to improve in practice. Based on their level of capability, firms are categorised into four groups: unaware/passive, reactive, strategic and creative. The framework stresses the intentionality of learning, implying the need for deliberate technological efforts to build capability. This framework provides a useful tool for policy makers in designing targeted innovation policies. The extent of attention to detail in innovation and technology management capabilities in this framework is, however, beyond the scope of this research.

Comparing technological capability[21] accumulation across several manufacturing sectors of South Korea, Kim and Lee (1987) suggest that the complexity of production technology and the scale of operations account for the emergence of different patterns among firms, in terms of the sequence of acquiring technological capabilities and sources of technological knowledge. According to Woodward (1965), industries can be categorised based on their production technology into small-batch (e.g. large machinery firms and giant shipbuilders), large-batch and process industries. As the evidence shows, all firms in the Kim and Lee's research, regardless of their industry and their scale, began by building production capability. However, small firms often pursue a strategy of self-reliance, while large firms tend to acquire technology from foreign sources and assimilate it. Specific to the scope of this research, large firms in small-batch industries rely heavily on foreign licensing and technical consultancies for product development and the installation of production processes at the outset, while their small counterparts often resort to limited

[19] Researchers have often modified the original model to fit their research purposes.
[20] There are other ways of defining latecomer technological capabilities in the literature. For instance, Gammeltoft (2004) breaks it down into four areas, namely acquisitive, operative, adaptive and innovative capabilities. However, an elaboration of these aspects by the author shows a very close resemblance to the previously mentioned conceptions of latecomer technological capabilities.
[21] Technological capabilities are divided into production capability (ability to operate and maintain production processes), investment capability (ability to design and erect new ventures and expansions), and innovation capability (ability to generate new products and processes and to improve existing ones).

internal efforts, focusing more on reverse engineering, informal methods of technology transfer and collaborating with local R&D institutes. One reason for this difference is suggested to be the product being less sophisticated in the case of small firms. An interesting pattern emerging from the comparison of the industries is that small firms in small-batch industries remain at the technological capabilities stage while their large counterparts move to build their innovation capabilities. Furthermore, compared with large-batch or mass production firms, large firms in small-batch industries are not so concerned with investment capabilities, probably because increasing their capacity is just a matter of providing capital. After building their production capability, firms with small-batch production technology are more concerned with their innovative capabilities to improve their products, while process technology firms focus more on investment and innovative capabilities, and large-batch firms follow a linear path from investment capabilities through to innovative capabilities.

Kim (1980) identifies three stages of evolution in the technological capabilities of the Korean consumer electronics industry: acquisition, assimilation and improvement. At the first stage, latecomers import packaged, mature foreign technologies and focus on implementing a production process to produce fairly standardised products. The firms operate in a low competition local market, and rely on foreign experts for technological efforts. The emphasis of technological activities at this stage is on engineering instead of on research and development. At the second stage, technology is assimilated for diversification purposes, and local technical experts and supplier firms become critical, as opposed to foreign expertise. The emphasis is on engineering and limited development activities. Finally, local firms attempt to improve technology and increase the efficiency of processes by deploying indigenous capabilities in the third stage. The emphasis turns to research, development and engineering activities, and government policies shift to export promotion. Although this analysis depicts the wider context in which latecomer capabilities evolve it primarily relates to technologies at the maturity stage of the product life-cycle. Lee, Bae et al. (1988) suggest, however, that the same three stages can take place for technologies in the transition stage. Providing that indigenous capabilities are grown, latecomer firms may finally generate emerging technologies in the fluid stage to challenge firms in advanced countries. Nonetheless, it is plausible to assume that technology holders will be reluctant to transfer technologies in the transition state for competitive reasons. Furthermore, technological activities in the transition and fluid stages, especially research in emerging technologies, are advanced features for firms, probably more applicable to the stage of transition from latecomer to leadership strategies.

Rather than having a narrow focus on technological capabilities, Hobday (1995) investigates the growth of the electronics industry in four South-East Asian countries, namely Korea, Taiwan, Singapore and Hong Kong from technology, market and strategy perspectives. The emphasis is on how innovative combinations of technology and the market pathways of catch-up have led to success in these cases. Various firm-level variables are investigated in this research, including firms' strategies, processes, structures, corporate ownership, mechanisms of learning, sequences and the nature of technological activities in order to understand the evolution of capabilities. Hobday conceptualises a latecomer firm as being different from a leader or a follower firm. Leaders are defined as generating new products and processes to gain leadership advantages. Followers decide to move behind the leaders while they are connected to the advanced markets in which they compete with the leaders. Fast followers might have specific advantages over leaders by avoiding costly and risky investments in R&D and in developing new markets. By contrast, a latecomer firm[22] is defined as a manufacturing company (existing or potential) that faces two sets of competitive disadvantages to compete in export markets: technological disadvantages and market-based disadvantages. From a technological perspective, these companies are isolated from the advanced sources of knowledge, lacking in technological capabilities. From a market perspective, these firms lack the access to the advanced markets they wish to supply, they lack interactions with sophisticated users, and normally face undeveloped local markets.

The study shows how latecomer firms systematically relate technological accumulation to exports and export marketing channels, categorised as export-led technological learning, in order to overcome their two sets of disadvantages. Most of the learning mechanisms in the latecomer context, including OEM[23] and ODM[24], are dual purpose, providing market and technology access simultaneously. Latecomers work to couple technological and market opportunities, using market signals as a focusing device for technological learning. Latecomers go through stages of learning product and process technologies, starting with simple tasks such as assembly, and moving towards more complex activities such as process improvements and R&D. It is argued that innovation[25] develops out of the competition to manufacture goods for established markets, building a competitive advantage through reducing costs and continuous process improvements.

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[22] Mathews (2002) defines four criteria for a latecomer firm: (1) being a late entrant to an industry, not by choice but by historical necessity; (2) being initially resource-poor, e.g. lacking technology and market access; (3) intending to catch up as the primary goal; and (4) having some initial competitive advantages, such as low costs, which it can utilise to leverage a position in the industry of choice. This definition is essentially very similar to Hobday (1995)'s definition of a latecomer firm.
[23] Original Equipment Manufacturing
[24] Own Design Manufacturing
[25] The OSLO manual in 1992 categorised the novelty of innovative technological changes into: new only to the firm; new to the industry in the country or to the operating market of the firm; and new to the world. However, Hobday (1995) adopts the definition of innovation in latecomer context from Myers and Marquis (1969), Schmookler (1966) and Gerstenfeld and Wortzel (1977). In this view, innovation is defined as a product or process new to the firm rather than new to the world or the marketplace.

Although some of above studies, such as Kim and Lee (1987), include some examples of CoPS, Hwang (2000) focuses on the development of the aircraft industry in South Korea as a case of CoPS in a latecomer context. The evolutionary path of latecomer technological capabilities in this case is suggested to be building systems integration capabilities based on projects and moving up the system hierarchy of product. The latecomer capability started with the production capability of components at the bottom and the simple assembly of aircraft, before moving to sub-assembly sub-contracts from foreign manufacturers, tooling design and limited development capabilities of sub-systems, and finally to the most complex systems integration activities at the top, related to aircraft design, development and tests for low-level aircraft. However, Korean firms have not been able to transit to the stage of full systems integration in order to become involved in the design, development and marketing of high-level aircrafts. It is argued that capability building in CoPS in this case study has been heavily based on project-based learning through undertaking similar projects at each level of the hierarchy and moving to undertaking more sophisticated projects at higher levels of the hierarchy. Korean firms have relied on specific avenues such as licenses from foreign manufacturers, on international sub-contracting and help from US companies for military aircraft production in the local market to build their capabilities. However, Hwang primarily attributes the final failure of Korea to develop an internationally competitive aircraft industry to external factors, such as the small size of the local market, the technological characteristics of the product (requiring costly and risky investments), and government policies that were broadly suitable for mass-production industries. While valuable insights can be drawn from this study with regard to the evolution of latecomer systems integration capability, such as the focal role of the projects and the gradual shifts in the product hierarchy, Hwang's study speaks less about the pre-project and post-project stages of a CoPS project lifecycle.

Similarly, Tacla and Figueiredo (2006) investigate the evolution of technological capabilities in the Brazilian subsidiary of an international supplier of capital goods for the pulp and paper industry, an example of CoPS. This study deploys a modified framework drawn from Bell and Pavitt (1995), focusing on design and production processes and paying less attention to the important project aspects of CoPS. In addition, the study is disconnected from CoPS literature. However, the findings suggest that the latecomer CoPS firm functions at different levels of depth across various areas of its technological capabilities, implying that it is hard to provide an aggregate status of technological capabilities in the latecomer context. Tacla and Figueiredo's research also indicates that as the firm progressed to building higher levels of capability, functional areas became more dependent on each other, suggesting a kind of co-evolution among capabilities. While this study provides us with some useful insights into the nature and evolution of systems integration capabilities, the firm in question is a subsidiary of an international specialised supplier. This institutional relationship opens up certain avenues for access to technologies and markets, putting the case in some contradiction to the definition of a latecomer firm.

Lee and Chaisung (2001) investigate the accumulation of technological capability in the wider context of technology trajectories of an industry, similar to the approach of Lee, Bae et al. (1988). While the majority of the literature focuses on how latecomer firms acquire initial technologies and start to improve upon them or innovate from behind the frontier, Lee and Chaisung suggest that latecomer firms can leapfrog, skipping some of the stages in the technology trajectory that leaders have gone through in the past. For instance, sensing the trend towards discontinuing the use of carburettor-based engines, Hyundai focused on developing a new electronic injection-based engine. However, it is plausible to assume that Hyundai had plenty of technological experience in carburettor-based engine technology from installing such engines in cars and improving upon the technology. Furthermore, Hyundai had probably developed a certain level of technological capability before deciding to skip the development of this generation of technology. Therefore, leapfrogging strategies are more likely to be seen at the later stages of catch-up, for example during the transition phase to leadership, by which point the latecomers have grasped the technological knowledge, have developed internal research and development capabilities or have formed relationships with research and technology centres in the industry for building the confidence and capabilities to embark upon more risky technological activities.

While this section has focused on the evolution of latecomer capabilities in the context of catch-up, the transition from a latecomer to a leadership position has been less widely investigated in the literature (Chuang 2008). Leadership is identified as the stage in which latecomer firms approach the innovation frontier, beginning to compete on the basis of new products supported by in-house R&D (Hobday Rush et al. 2004, p1434). The focus in the previous stages is on building a base of technological capability for innovating from behind the technology frontier, including adapting and assimilating proven technologies, improving technologies and products for the local market and competing on the basis of cost. In the later stages, however, latecomer firms face a transition process to building strategic capabilities that enable them to challenge technology leaders (Dutrénit 2007). Hobday, Rush et al. (2004) indicate that although the number of potential cases of latecomer firms that have approached the frontier is not small, the literature has neglected the possible differences in the evolutionary paths and dynamics of capabilities at this stage between the catch-up context on one hand, and capability building in developed countries on the other. The existing limited literature, however, suggests that latecomer firms can go through an incremental transition to the leadership stage, following a portfolio of leadership, followership and catch-up product strategies (Dutrénit 2000; Hobday, Rush et al. 2004; Dutrénit 2007).

3.3.1 Implications for research

As this section has shown, the literature on capability building in the latecomer context has initially been concerned with the gradual building of a minimum base of capabilities to survive in the marketplace before transiting towards 'leadership' positions. Three broad themes can be identified in the literature: (1) the distinction between technological activities and technological capabilities; (2) learning as a process through which technological capabilities are acquired, maintained and flourished; and (3) the use of staircase models to organise data on the progress of technological capabilities.

Recognising whether or not a firm has passed a particular stage of the staircase is a challenge in empirical research on latecomer capabilities. Quantitative measures such as numbers of patents (output) or R&D investments (input) do not properly reflect the kinds of innovative activities that take place in the latecomer context, which usually include engineering and development efforts, in contrast with advancing the technology frontier through R&D in economically developed countries. Instead of quantitative indicators, latecomer researchers often use qualitative measures, relating different levels or depths of capabilities to the type of activities that can be enabled by each level. The stage of progress is therefore identified by observing the type of activities that firms perform in reality and ascribing them to the corresponding level of capability depth. In other words, the accumulation of a particular level of capability is normally identified when a latecomer firm performs an activity that it was not able to do before.

The latecomer firm theories on their own do not provide a framework for this study. The majority of studies in the literature are focused on high-volume, mass-production sectors, the subject of the unprecedented Asian export success. Furthermore, the models borrow ideas from the product life-cycle framework (Utterback and Abernathy 1975). In addition to the general limitations of the product life-cycle model for explaining technical change,[26] CoPS normally do not follow the suggested cycle. This point, combined with other well-recognised differences between CoPS and mass-manufactured goods, suggests that latecomers in CoPS may follow a different pattern of technological catch-up compared to high-volume, mass-manufacturing firms. For instance, while it is plausible for high-volume

[26] Hwang (2000) discusses a long list of limitations.

manufacturing latecomer firms to acquire a license to produce fairly standardised products for mass consumers, or to manufacture under a contract for leadership firms, i.e. the strategy of OEM described by Hobday (1995), this catch-up strategy appears to be impractical in the power plant industry where products need to be engineered and customised for each project. However, the literature provides us with useful conceptualisations of latecomer capabilities and alternative pathways of evolution for comparison purposes.

In some cases (see for example Hwang 2000; Tacla and Figueiredo 2006) where technological catch-up in CoPS has directly been studied, the focus has been on functional capabilities, paying less attention to project capabilities, especially the pre-project and post-project stages. However, political pressure on Iran after the 1979 Revolution and the embargos imposed by the US have created a different context for Iranian firms, compared to South-East Asian or Brazilian firms, for catching-up in CoPS. In this context, forging contracting partnerships with leading foreign systems integrators, or using the experience and resources of the US defence industry, as observed in Hwang (2000), for the purpose of learning complex technologies appear hard to realise. However, the existing literature provides us with useful insights into the nature and evolution of LSIC. For example, we expect that technological differences between hydro and thermal power plants will affect the evolution of LSIC in firms. We can also expect that catch-up in latecomer CoPS firms will be heavily reliant on projects, and the accumulation of LSIC will occur through moving up the hierarchy of systems integration from simpler tasks to more sophisticated ones. Therefore, the existing frameworks and insights from the literature on latecomer firms need to be amended for empirical research into systems integration of hydro and thermal electricity generation systems in Iran.

3.4 Summary

This chapter has examined three bodies of literature, namely systems integration in CoPS, capability development in advanced countries and latecomer firm theory, in order to assess their potential contributions to understanding the nature and evolution of latecomer systems integration capability (LSIC) in Iran's hydro and thermal electricity generation systems.

The literature on CoPS helps us understand the strategic role of systems integration capability in creating competitive advantage among leading suppliers of CoPS. The theoretical and empirical content of the literature provides us with an understanding of the nature of systems integration capability and its organisational and technological constituent parts, as well as generating some insights into the evolution of this capability.

However, the context and content of the literature is largely focused on developed countries and leadership strategies, so on its own it is insufficient for developing the concept of LSIC for the purposes of this thesis, mostly because the existing frameworks cannot capture the kinds of technological activities that occur in a latecomer context, which are mainly concerned with catching up and engineering, rather than extending the innovation frontier via R&D. The learning mechanisms identified to explain the evolution of capabilities are mostly inapplicable in a latecomer context. Therefore, existing frameworks, concepts and insights need to be amended for the latecomer context, and tested or assessed with regard to the actual evidence. This research will therefore extend the range of empirical research in CoPS industries by adding cases of the electricity generation industry in an industrialising country context.

Some of the most insightful literature on capability development and evolution concerns how the most advanced and innovative firms in developed countries can sustain their competitive advantage in the face of fast-changing business environments through reconfiguring and renewing firm-level capabilities. However, some elements of this literature are overly theoretical, and the underpinning definitions are sometimes unclear and tautological, for example defining capabilities in terms of abilities, where the definition of abilities appears synonymous with that of capabilities. The literature identifies several categories of capabilities and generates useful insights into the nature of capabilities and the types of micro elements of which capabilities are composed. It also suggests frameworks to describe the evolution of capabilities and the variety of internal and external factors that might affect the heterogeneity of evolutionary paths among firms. The frameworks, however, sometimes suggest a rather deterministic direction for evolution, ignoring the possibilities of capabilities remaining static or even degrading, which could well occur in a latecomer context, or even in an advanced country context if, for example, there is insufficient investment in capability improvement. The insights from the literature are helpful for developing a theoretical framework to be tested or amended in the latecomer context. Furthermore, an analysis of methodologies used in empirical studies of capability shows that an integrated framework consisting of measures for inputs into the process of capability building, outputs of the process and transformation methods of capabilities could well be useful for capturing the evolution of capabilities.

Latecomer firm theories relating to technological catch-up initially concerned the accumulation of a minimum base of capabilities to survive in the marketplace and innovate from behind the technology frontier, before transiting to 'leadership' status. The literature is, naturally enough, focused on the East and South-East Asian export success stories. Recent studies in Brazil and Mexico have shown similar transitions to 'leadership' within the Latin American context. However, these mostly relate to high-volume mass-manufacturing sectors rather than CoPS or project based industries, so cannot on their own provide a framework for this study. The Asian studies do however provide us with a useful conceptualisation of latecomer capabilities, as well as describing other pathways of capabilities evolution and giving us insights into the types of factors that can affect the processes of evolution. These studies therefore provide us with a useful comparison for the purposes of this thesis, but they do not on their own provide an understanding of the nature and evolution of LSIC. The well-recognised differences between mass-manufactured products and CoPS suggest the need for more research into the case of CoPS in the latecomer context, which this study seeks to undertake. There are some studies of CoPS in the latecomer context, but the paths of development seem to be highly contingent on the circumstances and histories of specific countries, further justifying the attention of this research to the specific case of capability evolution in Iran. Useful insights are suggested by the literature, so that it can be expected, for example, that capability building in latecomer CoPS firms will occur through projects and via a progressive move up the hierarchy of systems integration from simple to more complex and challenging activities. It is hoped that this research can further amend and develop the LSIC framework through a detailed empirical study of CoPS in the context of thermal and hydro electricity generation systems within Iran.

In line with the emphasis of the existing literature on the differences in systems integration across CoPS industries, the next chapter investigates systems integration in the international context of hydro and thermal electricity generation projects. It hopes to define the boundaries of the research and paves the way for developing the conceptual framework in the following chapter.

4. Chapter Four: Systems integration in the international context of hydro and thermal electricity generation systems

The previous chapter indicated that the hydro and thermal electricity project industry is an example of CoPS, showing that systems integration capability is a core capability of firms in this industry, as with many other CoPS. The previous chapter also examined the potential contributions of the extant literature to the aims of this thesis and provided some insights into the evolution of LSIC. The current chapter seeks to provide an understanding of systems integration capabilities in the global context of hydro and thermal electricity generation systems. This understanding will hopefully contribute to the thesis in three ways:

Firstly, it hopes to help define the boundaries of the research by placing the concept of systems integration capability within the context of the industry. This chapter identifies three possible levels of systems integration capabilities in the industry and gives some examples of the organisations that are involved at each level.

Secondly, the chapter on the development of Iran's electricity sector indicates that a dynamic perspective is required to analyse latecomer systems integration capabilities. The current chapter therefore investigates the dynamics in the global context to facilitate the analysis of past decisions regarding paths of development in the case study firms, their current positions and their decisions with regard to future development. The discussion on the global dynamics of demand, innovation and market structure hints at the possibilities for latecomers to collaborate with leadership firms to develop LSIC, and suggests the range and extent of technological and strategic options open to latecomers.

Thirdly, understanding the dynamics in the global context and in particular the dynamics of technological activities will hopefully help further operationalise the concept of LSIC in order to develop the conceptual framework in the following chapter.

The data for this chapter has been gathered from different sources. Annual reports and technical documents published by leadership firms, websites of several systems integrators, scholarly papers on the dynamics of the industry, textbooks on power plant engineering, procedural documents of prime contractors, professional magazines and market research reports have been the major sources of information.

The chapter is organised into three parts. The first section describes a set of general tasks in power plant projects and identifies three levels of systems integration capability in the industry. The second section looks at the global context to illustrate the current status of the industry and also the dynamics of demand, technological activities and market structure. The final section summarises the chapter and discusses some implications for the growth of LSIC.

4.1 Systems integration within the chain of activities in power plant projects

To discuss the nature and different levels of systems integration in power generation projects, this section starts with elaborating the set of tasks in a typical hydro or thermal power plant project. Figure 4-1 illustrates these activities. Although differences exist between the tasks of hydro projects and thermal projects, and project tasks might differ even from one hydro or thermal project to another, the picture has been simplified for analytical purposes. This section is largely based on the practice and experience in Iran, which have developed over time through cooperation with international consultants and leading suppliers. Furthermore, the literature on the industry with regard to other countries (Charoenngam and Yeh 1999; Ling and Lau 2002) and information gathered from websites of overseas firms has been extensively consulted to investigate the differences. Thus, it is expected that this description would be broadly valid in the global context.

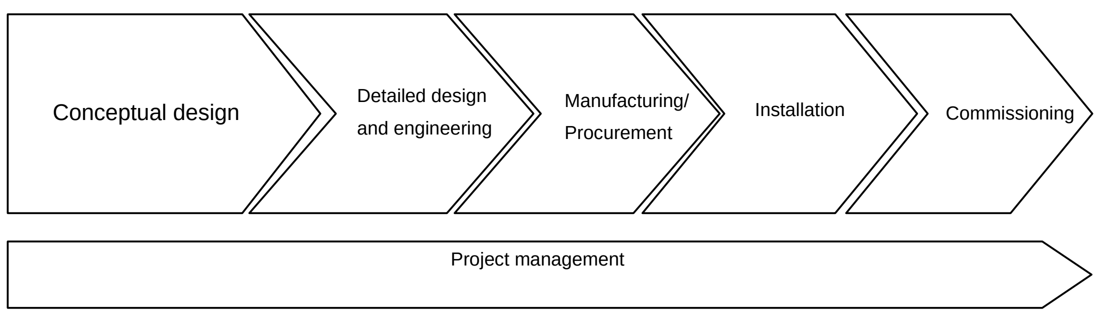

Figure 4-1: Chain of activities in a typical hydro and thermal electricity generation project (author's elaboration).

During the conceptual design phase, the key characteristics of the plant are specified in terms of the optimum number of power units, the capacity of each unit and the overall technological specification of the power systems. This phase often comprises several economic, technological, social and environmental trade-offs. In addition to deciding about trade-offs, designers sometimes suggest a list, called a 'vendor list', of qualified suppliers for core equipment. However, suppliers and prime contractors occasionally propose improvements to these initial decisions as new challenges or opportunities emerge in the later stages of a project. In the case of large hydro power plants, there is a considerable amount of construction work for dam in the later stages of the project. This thesis, however, is focused on the design, engineering, supply and installation of core equipment, namely turbines and generators, and non-core equipment.

The characteristics of core equipment are the main entry data to design activities for the other systems of a plant. The second phase normally starts with the design and engineering of core equipment. As every large hydro power site has its own profile of water flow rate and head, the hydro turbine has to be specifically designed for each project. Likewise, although gas and steam turbines are supplied in standard designs, these turbines have to be engineered in each project to reach the optimised performance in the project conditions and to satisfy the client's specific performance requirements. The design and engineering tasks relating to other systems of a plant begin after some features of core equipment have been specified.
[1] A share of engineering resources in this stage is spent on reviewing the design and engineering documents to ensure that the promises can be met and to prevent costly reworks in later stages. During the design review, the documents are normally checked against two criteria: (1) congruence with the conceptual design of the plant and the criteria for a balanced operation; and (2) capability of delivering what they promise.

The core equipment in gas fired plants are manufactured and assembled in factories and shipped to the project site. However, heavy components of hydro projects are fully manufactured or partly manufactured in factories in the form of smaller parts, which are then shipped to the project site for final adjustments and assembly[2]. For both core equipment and non-core equipment, inspection and quality control efforts are required to ensure that the specifications are met during manufacturing. Compared to core equipment, sourcing of non-core equipment is often simpler as these systems are technologically less complex and are supplied by a larger number of international suppliers.

During the installation phase, a large number[3] of technicians, engineers and local labourers work on the project site and use heavy industrial machinery to assemble and erect the power plant components. After installation, experts initialise the operation of systems and monitor them during the trial run period to remove possible defects. Depending on the contractual agreements, systems are usually guaranteed for a time period after the plant becomes synchronised with the electricity grid. Weaknesses in the design, engineering,

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[1] Engineers use specific terms to distinguish between different levels of engineering and design activities. For instance, (1) conceptual/basic design or engineering refers to activities to set the overall systems characteristics; and (2) detailed design and engineering refers to activities to specify the detailed characteristics of components, materials and manufacturing conditions.
[2] In the enormous Three Gorges project in China, core equipment was manufactured in workshops that were specifically built near the project site.
[3] The exact number depends on the project management method and the characteristics of the plant. For instance, in a hydro project in Iran, 1000 technicians and labourers were on the site for a period of 36 months (project documents, Farab).

manufacturing and installation of a power plant will show themselves during the long-term operation of the power plant in terms of, for example, emergency shut downs of the plant due to technical failures, higher operational and maintenance costs, and the actual efficiency compared to the promised efficiency of core equipment.

In addition to the technical work detailed above, extensive project management measures should be in place throughout the project to coordinate the network of multiple suppliers. During the project, project management deals with the coordination of design, procurement, installation and commissioning activities, financial risks, and possible legal disputes with participants and workers, among other things. Managing the financial resources for a project is a demanding task.[4] The extent of risks is more clearly understood when it is considered that thousands of tons of steel, concrete and mineral alloys are used in these projects and a large amount of energy is consumed to run the machinery on the project site. Small fluctuations in input prices can have tremendous effects on the project costs and returns on investment.

Within this general framework of activities, two other levels of systems integration activities can be identified in power plant projects, in addition to the necessary background systems integration tasks for the conceptual design of a plant. Feasibility studies and conceptual design in background tasks can be undertaken by clients or their consultants. In some project delivery systems,[5] consultants prepare the bid documents and evaluate the bids prepared by potential prime contractors.[6] A prime contractor such as Farab or Mapna is, however, responsible for systems integration of the whole plant.[7] Systems integration at this level concerns finding proper suppliers and sub-contractors and coordinating the tasks of detailed design, engineering activities for the balance of the plant[8] and managing construction and erection tasks. Systems integration at this level, among others, needs a technological understanding of the systems in a power plant, how they operate, interface with and affect each other.

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[4] A survey of 21 hydro power plants in the US which had commenced their operation in 1993 showed that the cost was between US$ 1700-2300 per kW of capacity (US DoE,2001). That study did not reveal the share of equipment in the total cost; however technical documents from Andritz Co. show that on average a total amount of US$ 280 per kW is spent on equipment.

[5] The generic term 'project delivery system' describes how the participants in a project are organised to interact and transform the project goals and objectives into a finished facility or service (Imam-Jomeh-Zadeh, 2005).

[6] To minimise the conflict of interests in the design of plants, regulation in some contexts requires that an independent organisation carry out the conceptual design phase. As a consequence, while prime contractors and leading firms might be able to conduct the feasibility study, they generally prefer to enter the competition at the later stages of a project when larger values are at stake.

[7] Farab introduces itself as a prime contractor capable of managing both dam and power house projects. It is capable of connecting with civil contractors and leading the partnership for this purpose.

[8] The balance of plant, or BOP, includes the engineering and integration of non-core equipment (systems other than turbines and generators in a plant) in order to ensure the efficient operation of the plant.

Clients in Iran, and probably in most other countries, often prefer to buy core equipment from leading international suppliers due to the critical role of core equipment in the economic viability of plants. Prime contractors therefore are either suppliers of these systems or form strong business relationships with leading suppliers. Only a small number of large multi-technology companies in the world, such as ALSTOM, GE and Siemens, have the capabilities to design, fully engineer and integrate core equipment of power plants. Although such leading international suppliers undertake complex design and engineering tasks with relation to projects, the prime contractor still needs to oversee and review the designs to ensure the promises will be met. For suppliers of core equipment, systems integration concerns detailed design, coordination of manufacturing and installation activities and technical supervision of those activities. In the case of thermal plants where general designs of core equipment can be used across projects, leading systems integrators undertake engineering activities for each project to improve the performance of systems in site conditions and possibly meet any unusual requirements of the client. However, the prime contractor might carry out the systems integration of non-core equipment by itself, or outsource it to specialised engineering firms. The press releases on the websites of leading international firms such as Siemens, GE and ALSTOM and their project references reveal that these firms are able to carry out all levels of systems integration in this industry, whatever their project strategy implies.

Table 4-1 summarises the levels of systems integration capability in hydro and thermal power plant projects. This classification does not necessarily show the levels of complexity in systems integration. Moreover, there might be some overlaps among the levels of capabilities, and a specific organisation might change its position from one project to another. This overlap does not necessarily suggest that learning systems integration at one level can guarantee success at other levels.

	Systems integration of core equipment	Systems integration of the whole plant and non-core equipment	Background systems integration
Capabilities	Understanding the client's requirements, detailed design, project engineering for optimum performance, project management, management of contractors in design, manufacturing and installation phase	Understanding the client's requirements, coordination of detailed design and engineering for core equipment, engineering for balance of plant, project management and coordination of contractors	Conceptual design of power plant, deciding over design trade-offs
Sample organisations	GE, Siemens, Voith-Siemens, Alstom, Mitsubishi Heavy Industries, Hitachi, Harbin, Dong fang, Mapna	Prime contractors e.g. Farab, Mapna, Cino Hydro, Harbin, GE, Siemens, Alstom	Clients and their consultants e.g. Aabniroo, IPDC, Monenco, Moshanir, Mahab Ghods, Lahmeyer, Acres

Table 4-1: Levels of systems integration capability in the hydro and thermal power plant project industry (author's elaboration)

4.2 Dynamics in the global context of projects

The discussion in this section is organised around three key aspects of the dynamics of the high-value high-technology capital goods industry: demand, innovation and market structure (author's elaborations on Hobday, 1998). Since a network of suppliers and temporary collaborations organised through a project is the main form of delivering a CoPS product, a global look at the market structure reveals the possibilities of collaboration and technological learning for latecomer systems integrators, and shows the effects on the technological options of the firm. Furthermore, the analysis of innovation dynamics will hopefully enrich our theoretical framework in terms of giving some insights into the differences between latecomer and 'leadership' systems integration capabilities.

World electricity demand is projected to grow at an annual rate of 2.7 percent in the period between 2007 and 2015, slowing to 2.4 percent on average in the following period between 2015 and 2030 (IEA 2009).[9] As of the end of 2008, 15 percent of global electricity consumption was produced by hydro plants, whereas the share from fossil fuels was about 69 percent (REN21 2010). Different primary energy sources act as substitute fuels, in economic terms, for electricity generation, and as a result the demand for a specific electricity generation technology depends on the position of its primary energy source compared to other sources. As such, the extent of investments in each type of electricity

[9] This projection has taken into account the impact of the current economic crisis on electricity consumption and investments in the sector. Another source for short- and long-term projections in the electricity industry is the US Energy Information Administration (EIA). However, the differences in figures between the International Energy Outlook 2009 Report published by the EIA and those of the report by the IEA that we have used in this section are not considerable.

generation plant fluctuates over time due to a variety of drivers emerging in each region. A full analysis of this dynamic is beyond the scope of the current research.[10]

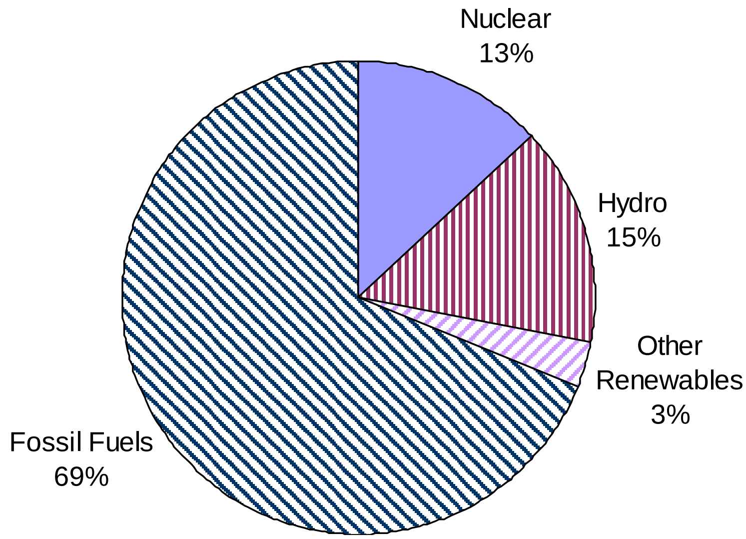

Figure 4-2: Share of electricity generated from each primary energy source of the whole global production of electricity in 2008 (REN21, 2010)

Global installed capacity of electricity generation is estimated to rise from 4509 GWs in 2007 to around 7820 GWs in 2030 according to the Reference Scenario in IEA (2009). Broadly relevant to this thesis, the estimations show that new gas-fired capacities represent 19 percent of this increase whereas new hydro plants represent 11 percent of the growth. Accordingly, around US$ 289 billion and US$ 167 billion (in 2008 terms) will be invested globally in gas-fired plants and hydro plants respectively from 2007 to 2015 (IEA 2009).[11]

The composition of this new demand is expected to create new opportunities for latecomer systems integration capabilities in these industries. Over 80 percent of the growth in electricity consumption from 2007 to 2030 is projected to happen in non-OECD countries, with the highest levels of growth occurring in Asia, the Middle East and Africa. Emerging Asian economies including China, India and the ASEAN countries will experience higher than average growth rates, at around 4.5-5.7 percent. In the case of hydro plants, OECD countries have already utilised most of their available sites, and the current complex regulatory procedures, as well as environmental opposition, restrict the process of building new large hydro plants. Rehabilitation of aging plants, investments in new pumped

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[10] Normally, the interactions between driving forces and restraining forces determine the direction of fluctuations at any time. For instance, in the case of hydro power plants, these forces include: the growth of sustainable development ideas, policies of reducing the dependency on foreign fuels in developed countries, rising environmental and social concerns about large hydro power plants, the unique role of hydro to compensate for the intermittent nature of renewable energies, the growth of the construction of new dams in developing countries which can be extended to hydro power plants, and last but not least expectations of fossil fuel prices and their availability.

[11] The relevant figures for the whole period (2007-2030) are US$162billion and US$528billion for gas fired and hydro plants respectively. Analysts have separated out the period 2007-2015 from the general trend because of the current economic crisis. The report, however, does not specify the share of large and small generation capacities in the overall figure.

storage and small hydro plants[12] as well as extending the capacity of existing sites will be future trends in these regions (ALSTOM, 2007). However, in South America, Africa and Asia there will continue to be strong demands for large hydro projects, mainly due to the abundance of feasible sites and the need for dams to provide drinking water for the growing population in these regions (Oud 2002; Papst 2008).

This market shift – the decline in OECD countries and the growth in non-OECD countries, including very large growth in China and India– may change the shape of the global competitive landscape. The emergence of new technological and manufacturing capabilities in the more developed regions to satisfy growing local demand is a possibility. Furthermore, the geography of demand is shifting to poorer countries, where clients might prefer solutions with lower capital costs and may need extensive foreign help, even to begin feasibility studies for a potential plant.[13] Meanwhile, due to the existence of a rehabilitation and capacity development market for existing plants, a service market for installed thermal plants and a market for providing engineering and equipment for the growth of capacity in OECD countries, leading systems integrators from economically advanced countries might be reluctant to directly enter into riskier business agreements with clients from economically weaker countries, creating new opportunities for the growth of latecomers in this industry.

4.2.1 Players in the global market

From the perspective of systems integration in this thesis, the global market for power plant projects can be divided into two segments, namely systems integration of core equipment, and power plant/non-core equipment systems integration. Historically, leading suppliers of core equipment have also been active in the other segment; however it is not necessarily true vice versa.

Since a comprehensive report on the global players in hydro power plant projects could not be found, a well-recognised leader in the industry, ALSTOM Hydro, was instead chosen, and its competitors were identified. Three companies appear to be the major competitors in the global market: ALSTOM Hydro (France-Switzerland), Voith-Siemens (Germany-Austria) and Andritz Hydro (Austria). Although these three firms are from economically developed countries, four other large firms have emerged from developing economies, namely IMPSA (Argentina), Harbin (China), Dongfang (China) and BHEL (India). The following table shows the average market share of these major companies in

[12] Except for China and India, other countries have defined the following ranges of output for hydro plants: large hydro is from 10MW to 18000 MW, small is from 1 to 10 MW, mini is from 100 to 1000 kW, micro is from 1 to 100 kW, and pico is from 0.1 to 1kW (REN21 2008).
[13] This is true at least in the case of some African countries (Source: interviews).

2008. As Table 4-2 indicates, the combined share of the three largest companies represents around 57 percent of the global market, showing a high concentration ratio in the market. Moreover, the three firms from developed economies are the only suppliers who design hydro turbines.[14] It is safe to say, therefore, that this market, as a high-value high-technology capital goods industry, is dominated, from the technology and market perspectives, by firms from developed economies.

Firm	Market Share
Alstom Hydro	22
Andritz Hydro	19
Voith-Siemens	16
Others	41

Table 4-2: Approximate market share of the major players in the global market of hydro projects in 2008 (Andritz 2009)

Regarding combined cycle plants, before the surge of privatisation, most power plants in the world were built on a 'Design, Bid and Build' basis, in which public engineering organisations or their advisors designed the project and organised tenders for the construction phase (SKM 2009). Large international firms such as Siemens and GE took the role of prime contractors and supplied their own core equipment for projects. Legal and financial disputes with clients in certain jurisdictions have influenced the decision of those large firms to move away from EPC[15] contracting to an increasing focus on supplying core equipment and related engineering services in projects (SKM 2009). The design, engineering and supply of core equipment lie at the heart of sustainable advantage and capturing high added value in projects in this industry (Bergek, Tell et al. 2008).

During the early history of combined cycle technology in the 1970s and 1980s, several firms from developed economies supplied core equipment, including GE, Westinghouse, Siemens, ASEA, Brown Boveri, GEC, ALSTOM, Ansaldo, Toshiba, Mitsubishi Heavy Industries (MHI), and Hitachi (Bergek, Tell et al. 2008). From this list, only the first five companies had their own technologies, while the others were manufacturing under license. In response to the dynamics of the environment, ASEA and Brown Boveri merged with each other in the 1990s to form a new company named ABB. In 1999, ABB sold its business in this field to ALSTOM. Similarly, Westinghouse divested its related business to Siemens in 1998. Although MHI started as a licensee of Westinghouse, it took over Westinghouse's manufacturing business of large gas turbines in the mid-1980s. MHI

[14] Relevant empirical research could not be found to examine how far LSIC has advanced in these latecomers. Their project references, however, show that IMPSA is currently designing an advanced turbine and Harbin has experience of designing some hydro turbines.

[15] Under an EPC contract, the contractor takes up the Engineering and Procurement of the materials and components, and the Construction of the project. The EPC contractor undertakes these tasks either through its own labour or by sub-contracting parts of the work. Whatever arrangement is chosen, the prime contractor carries the risks of schedule and budget in return for a price.

enhanced its technological capabilities through the Japanese government's R&D programmes, and cooperated with Westinghouse in developing F-class turbines in 1989, gradually emerging as a new technology owner.

As such, currently four companies are the major technology owners of heavy duty gas turbines: GE, Siemens, Alstom and MHI, while other firms manufacture under license from these four companies. The growing market in large developing countries appears to have motivated the establishment of new gas turbine suppliers (SKM 2009), such as Dongfang Electric Company (DEC) in China, Bharat Heavy Electrics Ltd. (BHEL) in India, Doosan Heavy Industries and Construction in Korea and Mapna in Iran. Except for BHEL, which jointly owns its turbine business with Siemens, other companies from developing economies are manufacturing under license. As their project references show, these latecomer firms accept the EPC role in projects, supply core equipment,[16] carry out some engineering tasks in projects and have started to export their products into overseas markets. Despite the emergence of new players, GE was the market leader in 2009, having a share of more than 40 percent in the global market, followed by Siemens, MHI and ALSTOM (GlobalData 2010). The past records suggest that a similar pattern in the market share has been in place over time. For instance, in 2009 GE represented 41 percent of the global accumulated installed base of industrial gas turbines, followed by Siemens holding 17 percent, ALSTOM 14 percent and MHI 6 percent (AeroStrategy 2009)[17].

One feature of the global market for hydro and thermal electricity projects is relatively long-term stability at the level of systems integration of core equipment. As power plants are engineered and delivered after the order is secured, suppliers have to convince the client that their proposal is the best possible option in terms of the specific requirements of the project, and that the firm is capable of realising it. High cost, high complexity and the level of customisation in projects make clients conservative in their decisions regarding the choice of systems integrator or prime contractor. Clients normally prefer well-known suppliers with rich experience so that their capabilities can be trusted. Likewise, clients are more inclined towards suppliers with a long history and a stable situation as they have to rely on the suppliers for spare parts and technological services in the future. This is one reason, in addition to technological difficulties, why relatively long-term stability can be observed in the global market of core equipment systems integration, making entry into the market through normal market mechanisms difficult for new firms.

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[16] Relevant empirical research could not be found examining how far LSIC has advanced among these latecomers. As their websites show, these firms are manufacturing the gas turbine under a license, but the extent of their design and engineering capabilities is not evident.

[17] Based on this report, Mapna has delivered 2 percent of the global base of industrial gas turbines.

4.2.2 Dynamics of innovation

The literature recognises a number of idiosyncratic characteristics of innovation in CoPS. Hobday (1998) identifies two general trajectories: (1) through time many CoPS become larger, more costly, and more functionally and technically elaborate; and (2) system complexity can increase from time to time due to rising demands on performance, capacity and reliability. This section focuses on those dynamics more specific to hydro and thermal power plant projects.[18] The importance of client requirements in shaping the innovation trajectory of CoPS has been discussed in the literature (Hobday, 1998). The analysis in this section is structured around the dynamics of technical aspects of the demand.[19]

Combined cycle plants

Technologies in the combined cycle power plant industry are developing in response to a set of drivers. Traditionally, the demand has been focused on higher levels of thermal efficiency to improve the economic investment and reduce COx emissions. For instance, an increase of one percent in thermal efficiency can decrease operation costs by $20m over the lifetime of a typical 400-500 MWs combined cycle plant (Curtis 2003). The overall efficiency of those plants with the most advanced technology has dramatically increased over the past three decades, from a typical rate of 52 percent in early 1992 to current advanced designs with 60 percent or above efficiency rates (Gianfreda 2007). However, changes in the wider socio and economic environment have led to the emergence of new requirements, broadening the technological competition in the global market to provide plants with higher reliability, shorter start-up times, longer operational lives, higher fuel flexibility, lower NOx and COx emissions and lower investment costs. Nevertheless, increasing efficiency is still probably the single most important driver for innovation in this industry (Curtis 2003; Blankinship 2008).

Advancements in gas turbine technology are vital for fulfilling the above requirements, giving a strategic importance to this equipment in the industry. The development of heavy duty gas turbines for power generation purposes can be traced back to achievements in the aircraft engine industry, although aircraft engines are much smaller and lighter in weight (Watson 1997). While the scientific principles for improving the performance of gas turbines have been known for a long time, the predicament is to find the proper

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[18] Power plants comprise a large number of pieces of equipment and sub-systems. From a technological change perspective, each piece of equipment or sub-system might follow its own trajectory of technological change. For instance, the move from mechanical to digital technologies was a key technological change in the control systems of power plants. Changes in one specific sub-system might also require adjustments or changes in other sub-systems and occasionally even in the whole plant.
[19] Some engineering activities might be required to customise a component or a sub-system to fit the project conditions, e.g. the design of an exceptionally large draft tube. Although these types of engineering tasks entail technical challenges, they can hardly be identified as creating or representing technological trends in the industry.

technologies and concepts required in applying these principles. For instance, one traditional approach to increase the efficiency of gas turbines is to raise the temperature of the gases in the combustion chamber. Raising the temperature is not as complex as devising concepts, technologies and materials to ensure the reliable and economically feasible operation of a gas turbine in such a harsh environment.

The technological race in the industry is manifested through competition in introducing new classes or platforms of gas turbines. Successive classes or platforms represent a set of new concepts and technologies to operate in a higher inlet temperature, promising higher levels of performance. For large gas turbines, the industry uses a letter designation to identify the class, representing an overall measure of its air volumetric flow, its compressor pressure ratio, and, most importantly, its firing temperature (Zachary 2008). During the 1980s, E-class gas turbines ruled the market and F-class turbines were introduced in the early 1990s. Currently, leading OEMs such as GE, Siemens, MHI and Alstom manufacture variants of E-, F-, G- and H-classes. For example, the most advanced class at the moment is H-class, which works in temperatures as high as 1700C and promises thermal efficiencies of 60 percent or higher in combined cycle, while the F- and G- classes work at typical temperatures of around 1350C and 1500C respectively. When a gas turbine design is tested and commercialised, the design of the core engine remains almost the same across projects, but comparatively simpler engineering work is carried out in each project to customise some other components for supporting the efficient operation of the core engine under site conditions.

Significant increases in the efficiency of gas turbines require research into several technological fields, and often need access to external sources of knowledge and technology (Bergek, Tell et al. 2008). Developing a higher class often requires new concepts, improvements in the design of components and sub-systems, and the development of new materials or technologies to ensure reliable operation. For example, the introduction of the H-class was enabled by progress on several technical fronts, such as a fundamental change in the cooling systems for turbine blades and vanes (closed-loop steam cooling), the development of single crystal materials for blades (transferred from the aircraft engine sector), the transfer of thermal barrier coating technology from the aircraft engine industry and the improvement of emissions in combustors.

It often takes years to develop a new class of gas turbine[20] but when new classes are introduced they tend to remain on the market for quite a long time. Leading suppliers incrementally improve the performance of each class by introducing new variants. For instance, GE introduced its E-class back in 1968, but in 2010 was still manufacturing some variants of the E-class for its clients all over the world. When a new class is introduced, materials, technologies and concepts developed for this purpose can be used to improve the performance of previous classes and offer improved variants of them. For instance, GE has used the materials developed for its H-class to improve the F-class, resulting in an increase of 5 percent in its power output and a 1 percent increase in its thermal efficiency (GE 2008). Occasionally, the accumulative effect of improvements in previous classes erodes the performance lead of new classes. For example, the G-class turbine of MHI (501G) started off by enabling a combined efficiency of 58 percent in 1999, but incremental improvements through time have increased the efficiency to 59.3 in its recent variants (Blankinship 2008).

The introduction of a new class is often followed by a series of after-launch improvements to rectify any emerging technical problems during the operation of new turbines. The history of gas turbine technology has records of costly blade failures, compressor disc cracks and vibration problems after the launch of new models (Smith 2003). Electricity generation companies have therefore become more cautious in the early deployment of new models, preferring instead to buy improved variants of previous classes.

The nature of technological developments in this industry poses significant challenges to latecomer firms wanting to enhance their capabilities. Firstly, designers in this industry have traditionally benefited from progress in the aircraft engine industry. The development of the F-class by GE drew considerably on ideas and technologies developed through the bypass jet engine programme of the late 1960s (Bergek, Tell et al. 2008). Similarly, certain technologies for the development of the H-class were transferred from the aircraft engine industry (Curtis 2003). However, the development of the H-class required other innovative concepts without precedents in the aircraft engine industry. Aside from GE, which is active in both aircraft engine and heavy duty gas turbine fields, other leading suppliers of gas turbines have a history of forming partnerships with aircraft engine firms (Bergek, Tell et al. 2008). The market for advanced materials, coating technologies, casting techniques and cooling systems in the aircraft engine industry was

[20] As the discussion in this section shows, the type of capabilities needed to develop new classes of gas turbines closely resemble diachronic systems integration capabilities as defined by Prencipe (2003), whereas the capabilities required to engineer the gas turbines for each project and the capabilities required for devising incremental improvements in a specific class correspond more with synchronic systems integration capabilities.

developed as a result of the multi-billion dollar military jet engine programmes of the US DoD and their European counterparts (Watson 1997).

Secondly, new classes are developed through costly and long-term development projects, often with the active contribution of governments, universities and component suppliers. For example, Siemens-Westinghouse and GE participated in the ATS (Advanced Turbine Systems) programme of the US DoE to realise considerable improvements in gas turbine performance. This eight-year programme started in 1992 and its costs were shared between participating firms, universities and the government. GE and Siemens both formed a network of utility companies, university centres, national laboratories, component manufacturers, firms specialised in high-precision engineering and aviation industry firms to develop the required technologies and concepts. The result of this joint programme was the introduction of GE's H-class and Siemens's 501G turbine. Similarly, MHI has recently become a member of a four-year national project in Japan to develop a new class of gas turbine with 1700C inlet temperature (Tsukagoshi, Muyama et al. 2007).

Thirdly, building full-scale prototypes of new designs is very costly, and although developers use simulation programs and scale models to test new designs, unforeseen behaviours tend to emerge during the operation of early installations. Designers therefore often rely on sympathetic clients to allow the use of their power plants as demonstration sites of new models, and in return provide extra guarantees and technical support (Zachary 2008).[21]

Large hydro plants

Although the concept of large hydro power plants has not changed considerably since early 1930s (El-Wakil 1988), radical and incremental changes have taken place at the level of plant equipment. Due to the vital role of core equipment in determining the overall performance of plants, it is not a large surprise that drivers of technological change at the industry level directly affect the evolution of core equipment.

Suppliers of core equipment constantly improve their designs to offer systems with higher efficiency,[22] higher reliability, improved operational safety and higher congruence with environmental regulations (Bremond, Vuillerod et al. 2005; VSHPG 2006). In 1826, the first high-efficiency hydro turbine was designed which could transform around 80 percent of water energy into mechanical work. Two decades later, the Francis turbine was

[21] MHI owns a plant in Japan that has been used for installing and improving new systems before their market launch (Zachary 2008).
[22] This is the mechanical efficiency of the turbine, which is defined as the amount of water energy that a turbine can convert into mechanical work.

introduced promising an efficiency rate of 90 percent or above. Since then, increasing the efficiency rate of turbines, sometimes at the level of only one digit has been at the centre of global technological competition.[23]

Two evident paths of technological progress can be identified in the industry. Firstly, the propensity of clients has shifted over time towards larger output units, leading to a reduction in the number of power units in a plant. Figure 4-3 shows how the output power of Voith-Siemens designs has changed considerably over time. From a technical perspective, plants with fewer power units need less investment in BOP, offer higher economic feasibility and show better mechanical characteristics (Couston, Bermond et al. 2006). However, the possibility of emergent properties and unexpected events increases as a hydro turbine grows in size. Even leading international systems integrators face high levels of risk in extrapolating their experience from smaller turbines to designing in larger dimensions (Bremond, Vuillerod et al. 2005). The design of larger turbines needs original research in the hydraulic and mechanical aspects of the equipment, and improved instrumentation and data-processing techniques to gather a wider set of data during modelling and testing activities.

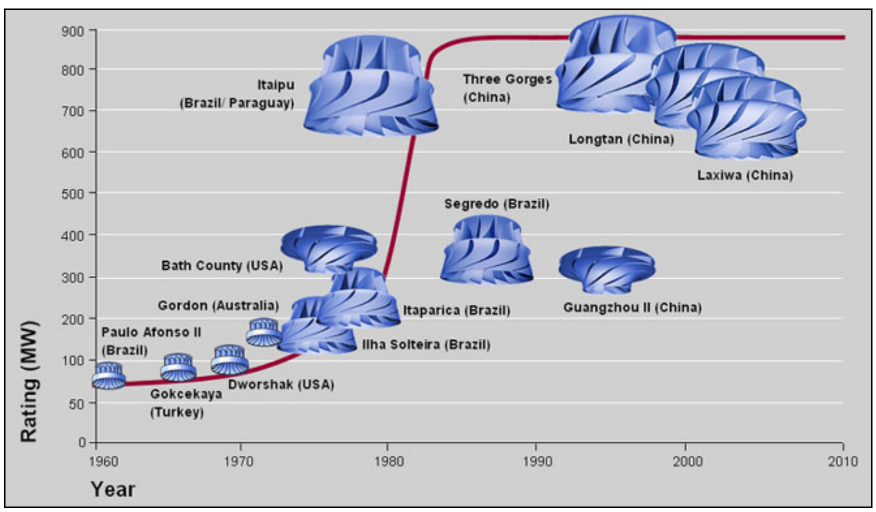

Figure 4-3: The evolution in output of hydro turbines designed byVoith-Siemens (website of Voith-Siemens)

Secondly, the trend is towards developing turbines with higher levels of environmental friendliness.[24] Although hydro power is one of the cleanest and most efficient methods of power generation, there are environmental concerns over the construction and operation of large plants. One of the environmental concerns relates to fish mortality and the

[23] Current advanced large hydro turbines can convert more than 90 percent of water energy into mechanical work. The choice of the type of hydro turbine for each project depends on the project conditions. Francis turbines are a popular choice due to their high efficiency and flexibility for installation in a wide range of large hydro plants.
[24] The capabilities to allow the development of new concepts of hydro turbines closely resemble diachronic systems integration capabilities (Prencipe, 2003).

compliance of released water with water quality standards. The DoE of the US initiated the Advanced Hydropower Turbine System Program (1994-2006) to help the industry overcome these challenges (USDOE 2001; Moreno 2008). This programme was jointly funded by the government and the hydro power industry. Two separate consortia of engineering firms, research laboratories and plant owners were awarded projects to develop new concepts. One of the groups, led by Voith-Siemens, came up with some improvements in the current designs of Francis and Kaplan turbines to reduce their environmental impact. The other group, Alden Team, led by Alden Research Laboratory, came up with a whole new concept for hydro turbines, as Figure 4-4 shows. As a result of this programme, Voith-Siemens currently has environmentally friendly turbines in its product portfolio.

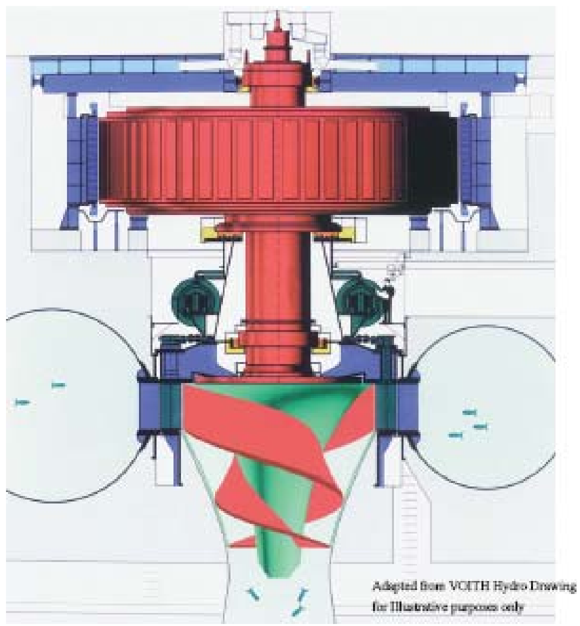

Figure 4-4: A new concept for fish friendly hydro turbine design by Alden Team

In addition to increasing the efficiency of turbines in hydro and thermal power plants, the industry has endeavoured to decrease the erosion of materials in rotating parts, to decrease the leakage of the flow, and to decrease vibrations during the long-term operation of the machines (VSHPG 2006).

A number of process-related innovative activities can also be identified in both hydro and thermal power plants. Prime contractors and systems integrators of core equipment seek innovative ways to reduce costs and lead times in projects. Development and deployment of sophisticated modelling tools, advanced calculation methods and 3D simulations have considerably expanded the possibilities for reducing the design time, increasing the accuracy of designs before production and increasing the efficiency of turbines (Smith 2000; VSHPG 2006). More broadly, the construction industry has been looking for innovative project delivery systems to match the changing business environment[25] (Miles 1995).

4.3 Summary

This chapter aims to build an understanding of systems integration capabilities in the global context of hydro and thermal electricity generation systems. This understanding provides us with some insights into the differences between latecomer and leadership systems integration capabilities and will hopefully help us operationalise LSIC for empirical research. The chapter has described the different levels of systems integration capabilities in the industry and has examined the current situation and dynamics of the global industry in terms of demand, market structure and innovative activities with the intention of enriching our analysis of the challenges and opportunities that latecomer firms face in their own development of LSIC.

Three levels of systems integration capabilities, namely systems integration of core equipment, systems integration of the whole plant (including non-core equipment) and necessary background systems integration, have been identified in this chapter, and some sample organisations specialising in each level have been indicated. As this chapter shows, systems integration of core equipment is vital to sustainable advantage and the capturing of high added value in projects. Although the available evidence indicates that latecomers might have progressed in terms of systems integration of the whole plant, the capability for full systems integration of core equipment appears to still be largely the territory of leadership firms from developed economies. The dynamics of learning, technology and the market might lead to changes in the profile of systems integration over time. The role of systems integration capabilities is not, however, confined to projects. Systems integration capabilities are also vital to innovations in the industry, since technological developments of core equipment require capabilities in several technological fields and the coordination of research and development activities across a group of partners.

The global demand for hydro and thermal power plants is projected to grow in both the short- and long-term, building an estimated market of around US$ 289 billion and US$ 167 billion (in 2008 terms) for thermal and hydro plants respectively between 2007 and

[25] In practice, a hybrid project delivery system may be adopted for any specific project. The following five systems constitute the main elements of hybrid options: (1) In-house: project finance, design and construction are all carried out by the project owner or sponsor; (2) Design/Build systems: the owner or sponsor provides the financial resources and a single contractor or organisation carries out the design and construction phases; (3) Design/Bid/Build systems: the owner or sponsor provides the financial resources and each of the design and construction phases are carried out by separate contractors; (4) Construction Management systems: the owner provides the financial resources, while an independent contractor coordinates the design and construction undertaken by separate contractors; and (5) Design-Build-Finance systems: an independent organisation carries out the three activities of finance, design and construction for the project owner or sponsor (Miles 1995; Konchar and Sanvido 1998; Ibbs, Kwak et al. 2003; Imam-Jomeh-Zadeh 2005). The main difference between systems is the extent to which the owner accepts the responsibilities and risks of project activities.

2015. The geographical shift of markets underlying this growth could significantly affect the opportunities open to latecomers. The majority of this growth, around 80 percent, is estimated to be taking place in non-OECD countries, with the highest growth rates in Asia, the Middle East and Africa, regions that are often considered as bearing higher risks for such projects. Leadership firms in developed economies are likely to be fully engaged with less risky markets for new plants, rehabilitation of and provision of maintenance products and services for existing plants in OECD countries in the future. The current propensity of leadership firms to shift away from accepting EPC roles for higher-risk clients[26] from less developed countries and move towards the supply of systems integration for core equipment further suggests new opportunities for latecomer systems integrators in the future, although in riskier areas.

From the market structure perspective, the evidence indicates that only a handful of leading firms based in economically advanced countries have the systems integration capability for core equipment. These firms dominate global markets. Due to the importance of reputation, and experience of engineering and designing core equipment to win bids, entry to the market through normal market mechanisms appears very challenging for latecomers.

The presence of some companies from developing economies in local markets, however, indicates that establishing some measure of LSIC is possible. The available evidence shows that some of these latecomers have started to export their services and products. Although empirical research examining the breadth and depth of LSIC in these cases has not been found, the emergence of these latecomers appears to be confined to developing countries with large and growing local markets, suggesting again a potential role for local markets and supportive clients in the growth of LSIC. Considering the importance of systems integration, it is expected that latecomer firms would need to form some sort of technological relationship with leadership firms to develop LSIC capabilities. However, one can imagine that if latecomers advance in building deeper capabilities, the continuation of such technological relationships might be jeopardised due to competitive reasons, as leading firms restrict technology transfer to protect their advantages.

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[26] Higher-risk clients in this context refer to those located in the countries or regions that pose higher risks to complex projects. Several categories of risks in overseas markets are identified in the literarture on project management which shape the perception of managers of risk in a specific market. For instance, a major category is security threats to personel and equipment, in particular, in forms such as abduction and burglary. Similarly, instability of political and macro economic situations pose challenges to projects in the forms such as damaging feasibility of projects due to dramatic changes in the inflation rate, or sudden changes in rules and regulations which could introduce new constraints on projects. Another common category in energy projects is the risk of accessing resources in the local area. For instance, machinery and equipment on the project site might break down, needing skillful mechanics and access to spare parts for bringing them back to operation. While several categories of risks might exist in any market, some of them might have a higher probability in some developing economies.

Several kinds of technological activities can be identified in this industry, occurring at both the level of core equipment and non-core equipment. A group of these activities concerns the engineering and customisation efforts to meet a project's requirements. While some of the customisations, such as designing an exceptionally long draft tube or optimising the design of a gate to fit the project conditions, pose moderate technical challenges, some others are highly challenging and contain unforeseen levels of complexity, the overcoming of which could potentially push the capabilities forward in the industry. An example is designing hydro turbines with unprecedentedly large diameters, which creates profound challenges even for leadership systems integrators. In essence, clients finance these types of technical developments to a large extent and often only trust leadership firms to overcome the technological complexities involved.

In contrast, the results of another group of innovative activities can potentially be deployed across many projects. They may be incremental or large-scale improvements in the existing systems, or new concepts for core equipment. Innovative activities of this kind often take a long time to generate results. Examples are the development of new classes of gas turbines or reducing the environmental effects of large hydro turbines, as described in detail in this chapter. These types of innovations are sometimes co-financed by the industry and governments with the intention of generating some sort of public benefit.

The global technological race in this industry is largely focused on the latter type of technological activities, increasing the performance levels of large hydro and gas turbines. Summarising some aspects of the underlying activities in this race can illuminate the scope of the challenges that latecomers face. Significant increases in the performance of turbines often require contributions from several technological and scientific fields in order to come up with new materials, concepts and systems. This process requires global leaders to cooperate with competent clients, leading laboratories, research centres and specialised suppliers. In the case of gas turbines, in particular, technological changes have been historically dependent to some extent on technologies and concepts previously developed in the aircraft engine industry. However, although models are made for testing during the design process, leadership firms often rely on sympathetic clients to allow them install full-scale models in their plants and improve upon them. Alternatively, some leading firms undertake huge investments to build their own test plants. The above points pose significant challenges for achieving advanced levels of systems integration capability in this industry. The latecomers are from contexts that presumably lack competent external partners and a strong local aviation industry. The latecomers might also face challenges in connecting with foreign advanced partners and may face reputational, financial and experiential barriers to pursuing advanced technological activities.

When a new concept or class of turbines is developed, however, it tends to stay on the market for quite a long time while suppliers incrementally improve upon its performance. This long market life can potentially allow latecomers to learn from a specific project or model. However, leading international suppliers are probably not incentivised to transfer the knowledge and systems integration capabilities that underlie the development of new concepts and technologies.

Accordingly, this chapter has raised a number of issues to be investigated in the context of Iran's hydro and thermal electricity generation projects, including the role of local clients in the growth of LSIC, changes in technical characteristics of demand and their impact on the evolution of LSIC, changes in the technological relationships of local firms with leadership firms, the evolution of the type of technological activities undertaken by latecomers and the evolution of the systems integration roles they have accepted in projects.

The next chapter deploys the ideas and concepts examined here and combines them with insights from the literature review to develop the conceptual framework for the empirical research of LSIC in the context of Iran's hydro and thermal electricity generation projects.

5. Chapter Five: Research Design and Methodology

The previous chapters have established why it is worthwhile to investigate the systems integration capability of high-value high-technology capital goods (CoPS) in the electricity sector of Iran as a developing country. They have also shown how the existing literature on latecomer firms and the literature on systems integration of CoPS in developed countries are not sufficient to explain the developments in the Iranian case. Furthermore, sector-specific information on 'leadership' systems integration and the possible challenges or advantages of 'latecomer' systems integrators have been analysed in the global context.

This chapter describes the elements of the research framework developed to empirically investigate the nature and evolution of latecomer systems integration capabilities (LSIC). At the core of empirical work are explorative case studies of two Iranian systems integrators in the business of engineering, designing and building large power plants. The case studies are developed through in-depth interviews supplemented with a variety of other types and sources of evidence.

This chapter is organised into six parts. The first section lays out the conceptual framework for the research. It combines existing definitions and approaches from relevant bodies of literature and breaks down latecomer systems integration capability into its three core constituent parts for research purposes. The second section proposes sub-questions for this research derived from the above conceptual framework. The third section justifies the choice of case studies as a research strategy in this thesis, explains the selection of the case study firms and points to relevant data about the evolution of systems integration capability in a latecomer context. The fourth section discusses the main sources of evidence and explains the processes for data gathering. The fifth section describes the approach to analysis and reporting. The final section summarises the chapter.

5.1 Conceptual framework

This research aims to understand the nature and evolution of latecomer systems integration capability (LSIC). Since systems integration is understood as a capability in this thesis, the definition of 'latecomer', 'capability', 'systems integration' and 'systems integration capability' are at the core of our framework. As a provisional way of roughly defining the concept of latecomer systems integration capability, we begin by taking the existing definitions from each relevant area of literature.

5.1.1 **Latecomer**

The concept of latecomer and latecomer strategy can be traced back to the ideas of Alexander Gerschenkron, an economic historian, in his attempts to analyse the late industrialisation process in backward European countries throughout the nineteenth century up until the beginning of the First World War (Gerschenkron 1962). Gerschenkron studied the differences in the speed and character of industrialisation processes in backward countries, i.e. other European nations that had started the journey at a later time, compared to an established industrial country like the UK. The differences, according to his work, originated mostly from the specific state of economic and social development in latecomer nations at the time they started the industrialisation process, conferring potential advantages and disadvantages upon them. Although Gerschenkron's study concerned developments at the country level, subsequent scholarly works have modified the concepts to be applicable at the level of firms attempting to enter into global competitions from a latecomer country context (Hobday 1995; Mathews 2002) .

Based on Hobday (1995),[1] for our research purposes, a latecomer is defined as a firm that faces two sets of competitive disadvantages in the market. The first disadvantage is that the latecomer firm is technologically behind, arising mostly from the fact that the firm is located in a developing country. A latecomer firm works in isolation from the world sources of science, technology and innovation, and its surrounding system of innovation (Freeman 1987) is poorly developed.

The second disadvantage is that a latecomer firm is dislocated from international markets, typically deals with underdeveloped, small, local markets and interacts with unsophisticated users. Based in a developing country, a latecomer firm lacks the opportunities to form user-producer linkages with the sorts of advanced customers that normally exist in developed economies. Many studies show the importance of user-producer linkages in innovation and industrial development.

However, latecomer firms may have cost advantages over leaders due to the access they may have to potentially cheaper resources. They may also have advantages in knowing more about the local market conditions and the required modifications for adapting technology to local needs. The main challenge of a latecomer firm is therefore to devise a strategy to overcome the initial market and technological barriers to entry, and to consequently upgrade its position over time.

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[1] As presented in the literature review chapter, Hobday distinguishes latecomer firms from leader and follower firms in advanced economies.

5.1.2 Capability and evolution of capability

As Chapter Three has shown, the subjects of capability and the evolution of capability have been researched quite extensively in the management literature (Helfat 2000; Dutrénit 2007; Teece 2007). One can easily populate dozens of pages containing only the names of relevant references. This literature, however, suffers from confusion in its terminology (Dosi, Nelson et al. 2001) and in tautological definitions (Williamson 1999; Priem and Butler 2001; Arend and Bromiley 2009). While it is not within the scope of this chapter to discuss the variety of definitions and empirical approaches used in the literature, this chapter will introduce a working definition of capability, attempting to overcome the problem of tautology (e.g. 'capability is the ability to perform a coordinated set of tasks') and to build a starting point for our empirical research.

Capability can be defined as a collection of attributes that permit the holder to conduct an activity.[2] Although this definition is applicable to almost any type of activity, such as running or golfing, the thesis focuses on firm-level capabilities and looks at them mainly from a technological perspective. The attributes in question therefore may include knowledge and skills embodied in individuals or groups, physical capital, such as equipment and IT systems, and organisational capital, such as structures, processes and relations within the organisation, or linkages with other organisations.

An organisation may require non-technological attributes, such as appropriate structures or inter-organisational linkages, to conduct a technological activity. Therefore, non-technological attributes often become inseparable from and indispensable to technological capabilities. Accordingly, although our focus is mainly on the technological side, we also examine how technological capabilities are organised (e.g. within project and functional structures).

Capability (weak or strong) obviously influences the performance of the related activity, but other (internal or external) factors, such as forces of competition or temporary internal conflicts, may also explain the performance of an activity and changes in performance over time (for example with few if any changes in capability). A capability is contextual in the sense that it can only be meaningful in relation to a particular activity in a particular context (such as a market or an industry). In this sense, it has a subjective as well as an objective dimension. Outside its context, a capability may be meaningless or may even become an obstacle, preventing an organisation from responding to a new

[2] Personal correspondence with Prof.Mike Hobday.

situation.[3] As such, capability on its own cannot provide a full explanation of performance, and this thesis therefore attempts to avoid the common error of assuming that the capability of a firm can explain its performance (Arend and Bromiley 2009).

Capability has a cumulative nature and can be built, but cannot be built overnight. In fact, capability, as a collection of attributes, tends to remain dormant, grow (become stronger or deeper) or even decline (degrade) over time. It grows, for instance, if the related activity is exercised or if the organisation invests in its underlying attributes. Likewise, the capability may gradually fade away if the activity is not repeated, if the firm does not invest in it, if the firm incidentally loses some of its underlying attributes, such as human resources, or if the organisation decides intentionally to degrade the capability. Moreover, it is likely that approaches to performing an activity or expectations of the activity change over time, requiring changes in the attributes underlying the capability. For instance, knowledge of computer applications has become an attribute that is often necessary for modern design capabilities, while the requirements were different not very long ago. Accordingly, capability is very likely to evolve, but not necessarily in any deterministic direction or in a life cycle manner as suggested by some (Helfat and Peteraf 2003).

In order to capture the evolution of capability and the dynamics behind this evolution, this thesis suggests a simple process model:

a) inputs such as people, leadership, investments, goals or aspirations;
b) transformation mechanisms, such as learning and training efforts, repetition of activity, technological efforts, key events and projects;
c) outputs such as new or modified systems, market confidence, market success (or failure in the case of capability downgrading), improved technological performance, expanded possibilities, improved strategy.

Although this simple process model could be applied to capture the dynamics of a wide range of capabilities, it will be further developed in the following sections to incorporate the particularities of the evolution of systems integration capability in a latecomer context.

[3] Leonard-Barton (1992) describes some cases where the core capabilities of past could become the core rigidities of the present.

5.1.3 Systems integration

The systems integration concept has been used in the CoPS literature to refer to a particular activity (or set of activities), a particular capability, and a mode of organisation (Prencipe, Davies et al. 2003).

Systems integration can be defined as a set of activities undertaken by an organisation to define and combine all the various knowledge and production inputs including, components, sub-systems and software, required to produce a product, system, construct, network or service (Davies and Hobday 2005). Systems integration has two faces. The first face concerns the internal activities of an organisation needed to develop and combine the inputs. The second face is related to the external activities to integrate tangible and intangible inputs from other organisations to produce ever more complex products and services. This aspect of systems integration has attracted more attention in recent years. Systems integration, defined as an activity, is a multi-perspective concept which is best defined in relation to: (a) the nature and scope of the system[4] being integrated, and (b) the nature of the integration process. This thesis focuses on systems integration in CoPS.

A systems integrator is the organisation (or organisations) that carries out the systems integration activity. Two points in this definition need further elaboration. Firstly, the suggested integration not only includes the integration of physical components, but also various knowledge areas and skills. Secondly, all the inputs are not necessarily sourced internally within the firm. On the contrary, central to the nature of systems integration is the coordination of external sources, this being either an organisational or a technical coordination (Prencipe 2003). However, in delivering a high-value high-technology capital good (CoPS), several organisations might be involved in the systems integration activity, depending on the nature of the system and the local division of labour to deliver the system. In fact, systems integration might convey different meanings for and might require distinctive sets of skills from each organisation involved in the task (Gholz 2003).

Following our definition of capability, systems integration capability can be defined as a collection of attributes that permit a systems integrator to conduct the systems integration activity. Broadly speaking, systems integration capability permits the systems integrator of a CoPS to understand a complex system of technologies, products and services, to understand the knowledge areas underlying them, and to define and combine together all the necessary inputs required to realise the system in response to the evolving needs of the client. From a technological perspective, systems integration comprises the

[4] Hobday, Davies et al. (2005) offer a first attempt at specifying the system in this definition.

capability in product development to introduce incremental or radical innovations in the product-system. These innovations can happen at the level of subsystems/components or at the level of the whole system, and encompass efforts to either stretch the current architecture to its limits or to search for new architectures (Prencipe 2003).

For our research purposes, systems integration capability can be further operationalised into three core constituent parts, as the following figure shows.

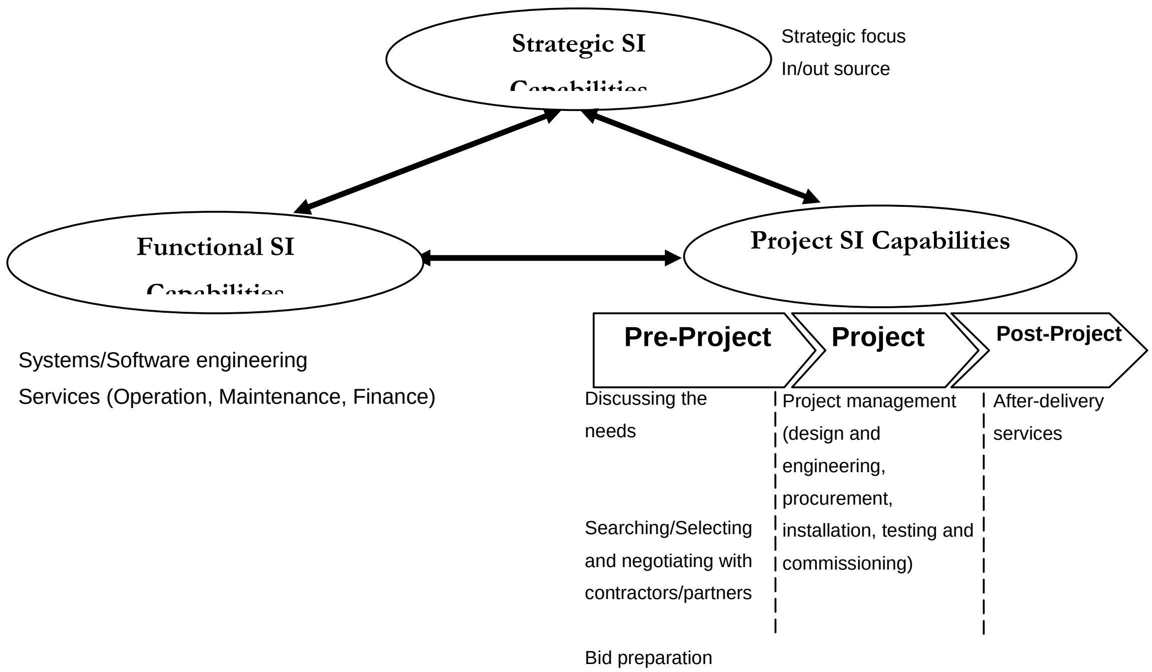

Figure 5-1: Constituent parts of SI capability: adapted from Hobday, Davies et al. (2005)

The current literature on systems integration investigates the concept within the context of economically developed nations and within firms that move at the technological frontier of their industry: what could be known as leadership systems integration, using the terminology of Hobday, Rush et al. (2004). The following paragraphs summarise the key dimensions of leadership systems integration borrowed from the extant literature, and combine them with some propositions as regards latecomer systems integration. It is one of the contributions of this thesis to elaborate the dimensions of latecomer systems integration capability.

1. <u>Functional Systems Integration Capability (Functional SIC)</u> is constructed around the core technical fields of systems engineering, software engineering and services such as training, maintenance and finance required for delivering partially or fully integrated

solutions.[5] It covers attributes allowing the firm to set the product's concept design, decompose it into sub-systems, coordinate and technically oversee the network of suppliers to perform detailed design and manufacturing of the sub-systems (sometimes this coordination and technical supervision is called 'design review' and 'quality control' in practice), recompose the whole system, supervise system testing and provide post-project services if the contract mandates it. As such, functional SI capabilities are mobilised in projects in order to realise a system or to develop a new product/solution. The new product could originate from the existing families of products or from a new family. The new product therefore could accompany innovations at the level of component/sub-system or at the level of the system architecture.[6]

2. Project SIC refers to the mainly organisational capabilities that permit the conduct of (1) pre-project, (2) project and (3) post-project activities in a CoPS project, covering a wider scope than the common practice of project management (e.g. in the PMBOK Guide[7]). Project management is concerned with realising the output subject to the agreed parameters of time, cost and quality.[8] It specifically includes the management of design, procurement, installation, testing and commissioning activities in a CoPS project. This definition, however, corresponds only to the second element of project systems integration capabilities, while Project SI capabilities, in addition, permit suppliers to engage with customers to identify their needs at an appropriate time, discuss the needs, configure a proposal/offer to address the needs,[9] secure resources such as finance and contractors' capacity, devise the appropriate project (temporary) organisation to coordinate external resources and deploy the experience from previous projects. The lifecycle of a project can be extended into the operation and service of installed systems if the contract requires this.

3. Strategic SIC refers to a collection of attributes required for continually optimising the position (strategic focus) in the industry value chain, making effective decisions on the extent of outsourcing, choosing technologies and partners to work with, getting out of unattractive markets and gearing the capabilities towards new promising markets in a

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[5] Systems engineering is primarily a technical task to draw up a set of overall specifications that map the performance of each sub-system in a complex system and its interactions with every other system. Other tasks include the evaluation of sub-systems during development, the planning of their integration, the controlling and testing of sub-systems and the assessment of the operational environment (Hobday, Davies et al. 2005).

[6] Prencipe (2003) uses the term 'synchronic' to refer to SI capabilities for developing new products/solutions within the limits of existing architectures, and 'diachronic' to refer to SI capabilities required for developing products/solutions offering new architectures.

[7] A Guide to the Project Management Body of Knowledge (PMBOK Guide) is a set of standard terminology and guidelines for project management based on generally accepted practices in the field. The Project Management Institute is the publisher of this guide. The latest edition was published in 2008.

[8] Pinto and Kharbanda (1995) recognise customer satisfaction as a fourth element.

[9] It often includes the time, cost and quality plan.

timely manner. It inevitably requires maintaining intensive relationships with suppliers and customers, and being alert to changes in the environment.

Leadership systems integration capability permits systems integrators to perform innovative activities within the limits of current architectures or to explore the potential of new architectures. For instance, as discussed in Chapter Four, in addition to undertaking sophisticated engineering activities for the design and realisation of plants, leading systems integrators of hydro power plants are capable of developing new hydro turbines with unprecedentedly large diameter blades (stretching the current architecture to its limits), and of developing new architectures for fish friendly turbines. Similarly, leadership systems integration capability in thermal power plants allows suppliers to incrementally increase the performance of current gas turbines or to develop more sophisticated new generations with higher levels of efficiency and friendliness to the environment. In the latecomer context, it may also be expected to see the emergence of innovative latecomer SI capabilities in order that suppliers are able to improve on a system, intelligently adapt it to meet perhaps unusual local needs or even to design a simpler, lower-performance system.

Leadership systems integration in the power generation industry enables leading suppliers to carry out detailed design of core equipment, namely the turbine and the generator, in addition to the design of the whole plant. As was shown in Chapter Four, knowledge of detailed design and the ability to supply core equipment is central to the competitive advantage of companies like Siemens, Alstom and GE. In fact, certain clients, if not most of them, require the future would-be supplier of their power plant to be the designer and supplier of core equipment.[10] This capability gives certain flexibilities to leading suppliers in accepting various roles in projects depending on the situation, for instance as the prime contractor and supplier of core equipment, the prime contractor and supplier of core and non-core equipment, or just the supplier of core equipment. As the evidence shows, leading suppliers currently use this flexibility for their benefit, leaving the business of prime contracting in higher-risk environments to others and focusing on lower-risk contracts with the designated prime contractor to supply core equipment.

In addition, leadership systems integration capabilities confer the advantage on suppliers to cope with complex technical challenges arising from stretching the current architecture to its limits in projects. For instance, Alstom was the main participant in the Three Gorges Project in China; other systems integrators were involved, but the consortium relied mainly on Alstom to deal with the emerging technical problems of designing what

[10] Clients often define it as a qualification criterion for participating in bids.

were then the largest hydro turbines in the world (Couston, Bermond et al. 2006). Considering the level of uncertainties, clients tend to outsource projects with unprecedented levels of complexity to leading systems integrators, hoping that their experience and knowledge in detailed design of core equipment will prevent catastrophe.

5.2 Research questions

Based on the conceptual framework advanced above, the main research question can be broken down into sub-questions to help realise the research objectives.

1. What is the nature of latecomer systems integration capability (LSIC) and how has it evolved over time?

a) What are the constituent parts of LSIC?
b) What are the depths and levels of these constituent parts? How did these change over time?
c) What were the pathways and mechanisms of capability development (e.g. between firms and across different types of capability)?
d) How did the building of LSIC take place? For example, what inputs were needed? What were the transformation processes? What were the outputs in terms of, for instance, new or improved systems, amended designs, market confidence, expanded technological possibilities and improved relationships with suppliers and customers?
e) What were the outcomes of LSIC building, for example in terms of business performance internally and externally, product/system development or value chain position?
f) What are the remaining gaps and limitations of LSIC building, and how can we explain differences in pathways and achievements among firms?

Answers to these questions will hopefully shed light on the drivers that have motivated company strategists and external policy makers to build LSIC, the types of hindrances and difficulties confronting the building of capabilities and the way these were addressed. By investigating the above questions we hope to provide some suggestions in terms of business strategy and government policies to support the further development of LSIC.

5.3 Research Design

This thesis is about the nature and evolution of LSIC. The issues of research, the nature of our questions, and the current state of the related literature indicate that an exploratory research study would suit the objectives, identifying and examining the dimensions that are little known about, rather than measuring their rate or frequency or testing propositions suggested previously in the literature.

The purpose of an exploratory study is to generate new empirical evidence, where any such evidence is lacking, to generate relevant concepts, frameworks and new empirical categories and to generate plausible hypotheses or propositions for further studies. As reviewed in the literature section, the current literature does not provide the thesis with a fairly good, solid 'theory' or framework to compare the practical examples with to arrive at conclusions. By comparison, a looser collection of underdeveloped theories and concepts are in place, which this research applies to the evidence in an 'inductive' way to generate concepts and then relate them to the loose theory.

The choice of case study as a research strategy[11] in this thesis is justifiable from various angles. As the conceptual framework shows, capabilities are firm and context specific, and the attributes underlying them can be distributed across a firm. On the other hand, the empirical study on the evolution of capabilities requires a detailed, in-depth assessment of the processes of change by gathering data from several levels in a firm, including functional and cross-functional levels, and from the wider external context over time to capture the dynamics. The case study is a suitable strategy for such contextual and holistic research (Eisenhardt and Graebner 2007). It is not surprising therefore to see that case study is a preferred strategy in the empirical literature of capability evolution (Ethiraj, Kale et al. 2005). From the perspective of the research questions, our questions are mainly 'what' and 'how' in nature, compared to 'how many' and 'how often', and the research deals with contemporary issues. The framework elaborated in Yin (2003) suggests that a case study strategy is appropriate for such questions.

In project-business firms, the development of the underlying attributes of capabilities can occur at both the project level and the wider firm level. At the project level, these developments may involve other firms and organisations, while the firm is the chief receptacle for long-term learning. Specifically in terms of our conceptual framework, the evolution of output measures of LSIC can mainly be observed in projects, in forms such as taking over tasks from foreign systems integrators. However, the factors or dynamics behind the evolutionary path can be more appropriately studied at a firm level. For instance, a specific level of capability develops as a result of performing certain projects but can degrade over time as the firm fails to retain underlying knowledge, or the firm decides to quit the markets which require such capability. Accordingly, the definition of an

[11] As Vershuren (2003) describes, research strategy refers to a coherent set of methods, techniques and procedures for generating and analysing the research material, as well as the way in which the researcher looks at reality and conceptually designs the research project.

embedded design in which the primary level of data gathering is the firm and which incorporates projects as sub-units promises to serve the research purposes (Verschuren 2003; Yin 2003).

The introduction to the thesis justifies the focus of our research on the electricity generation sector in Iran. Among the Iranian firms involved in the systems integration of power generation systems, Mapna[12] and Farab were chosen for the case studies. These firms were the only local systems integrators in large power generation projects until 2008, when the Ministry of Energy supported the entry of new local contractors. These new contractors have often been subcontractors of Mapna and Farab in the past. These new competitors usually act as pure project management companies, lacking engineering and manufacturing capabilities. Farab and Mapna, however, have an appropriately long history and experience in the development of systems integration capabilities, while their local counterparts are in comparison newcomers to the field.

Farab and Mapna started their business in the 1990s and had been operating for less than 20 years at the time of this research. At the outset, being affiliated to Iran's Ministry of Energy, the firms informally drew a border in the local market so that Farab focuses on hydro power and Mapna on thermal plants. Mapna started its business as a general contractor but gradually diversified to cover engineering, construction, finance and operation of large complex systems in the power, oil and gas sectors. It recently launched a new business in manufacturing cargo and passenger locomotives. Farab started with large hydro power plants but diversified into new markets including the local market for thermal plants (Public-Private Partnerships) and the oil and gas sectors.

The relatively recent success of these two firms in overseas markets for power plant projects indicates high potential in empirical research of LSIC in the Iranian context. Although the diversification of firms into markets for other complex projects will be touched upon as an indication of possible maturity in systems integration capabilities, the fieldwork focuses on the core business of Farab and Mapna, namely large hydro and thermal power plants respectively. In addition to making the research feasible within the scope of a PhD, this decision promises a deeper understanding of LSIC by focusing on the areas in which the firms have a longer history. The annual reports and current mission statements indicate that the two case study firms prefer to focus their technological learning activities on their respective core businesses.

[12] The expanded name in English is the Iran Power Plant Projects Management Company.

In this thesis, related aspects of projects, the firms and their context are investigated throughout the period starting from the firms' establishment. At the time of fieldwork, Mapna was involved in the design of projects and the manufacture[13] of core equipment of thermal power plants in addition to the final integration of plants. However, Farab was focused on project engineering and managed a network of foreign and local suppliers to source core equipment. Nevertheless, Farab appeared to have acquired the capability for designing the turbines and generators of hydro plants, in contrast to Mapna, which still relied on foreign licenses for manufacturing. These indications of possible differences in the scope and depth of latecomer systems integration capabilities provide a rich context to corroborate, internally explain the contrasting evidence, and draw cross-case patterns.

5.3.1 Evolution of latecomer systems integration capabilities

Following the discussion of a simple process model in the conceptual framework section above, it is necessary to elaborate on its elements in a latecomer context. Technological capabilities are investigated in the existing literature by measures such as R&D expenditure (an input element in our model) and patents (an output in our model) (Mansfield, Teece et al. 1979; Patel and Pavitt, 1997). Clearly, these are not only rough measures in the context of an advanced country but also hardly reflect the essence of technological activities in a latecomer context, which are expected to be more about engineering and improvement in nature (Bell, 2007; Hobday 1995).

The provisional definition of systems integration capability in the conceptual framework provides a basis for gathering the evidence on the evolution of the three core constituent parts of LSIC. Defined in a latecomer context, the thesis looks for evidence on inputs such as people, teams and investments going into engineering, modelling and understanding complex systems, and project management. For the transformation process, the research looks at learning processes such as knowledge transfer agreements, key technological events in projects, cross-functional change programmes and a variety of other organisational improvement efforts. As regards the output, the research looks at elements such as taking over tasks that were previously performed by leading foreign firms, successes, failures and the expansion of market possibilities. The study also looks at other possible outputs of the capability catch-up process in a latecomer context, outputs such as changes or modifications in products, components, systems, services and solutions, changes in the roles latecomer systems integrators play in projects, the level of dependence on foreign knowledge, designing products from behind the technology frontier, changes in markets and improvements in the performance of projects.

[13] It may encompass engineering activities to customise a system for each project, not necessarily the original design of that system.

Although the process model is largely able to capture the dynamics behind the evolution of LSIC, the research needs a method to assess the evolutionary paths of LSIC in firms. For this purpose, a simple set of staircases have been developed for LSIC to benchmark against the evidence. The evidence might support, refute or refine this benchmark model. Developing staircases is in line with empirical literature on the evolution of technological capabilities in the latecomer context (Lall 1992; Bell and Pavitt 1995; Figueiredo 2003). The staircases used in this research do not intend to imply a deterministic or linear path for the evolution of capability. They are simply a way of organising and benchmarking the data gathered. The following three tables further describe the levels of depth in the staircase model for each of the three core constituent parts of LSIC and present a sample of indicative evidence for each level. Categories in the tables are developed on the basis of insights gained from studying other models in the latecomer literature, the understanding of systems integration in the power plant industry as presented in the previous chapters, and discussions with informants during the preliminary stage of fieldwork. The final models emerging from the data analysis will form a part of the contribution of this research.[14]

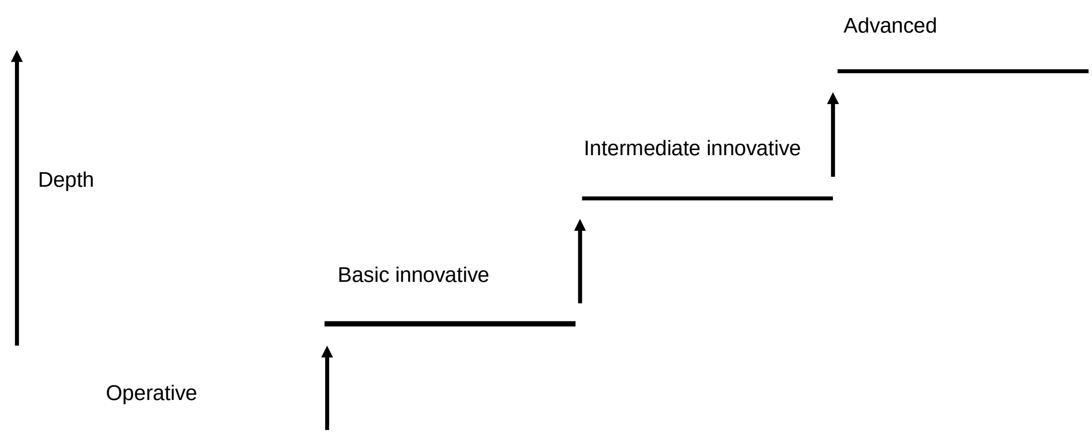

Figure 5-2: A simple staircase illustrating different levels of depth in latecomer SI capability

[14] These provisional definitions were revised and extended during the fieldwork and analysis stages. Figures 4-7 in the next chapter present the revised staircases after iterating between the evidence and the model.

	Latecomer Functional SIC			
Levels	Operative	Basic innovative	Intermediate innovative	Advanced
Brief description of the capability depth or level	Permits the systems integrator to carry out a power plant project according to specifications. Central expertise includes the knowledge of interfaces between components and the selection of equipment to optimally meet the overall specifications of the plant.	Permits the systems integrator to make improvements on the overall specifications and design of components to increase the efficiency of the project. It includes the capabilities to coordinate change across the supply network in order to accommodate innovations within the limits of the current architecture. These changes occur mainly in non core equipment.	Permits the firm to design core equipment of a plant. This design may accommodate certain localisations or modifications. Likewise, it could possibly target a lower performance system.	Permits the systems integrator to cope with the challenges of designing high-performance core equipment.
Indicative evidence in terms of the nature of underlying attributes or related activities	Sizing and selection of equipment and components according to the conceptual design. Design review of equipment and components. Knowledge of interfaces. Sourcing/Procurement. Quality control. Assembly/Installation. Testing and Commissioning. Operation during trial runs.	Understanding system behaviour and the function of components Design review of plant Capacity engineering (energy engineering), sizing and selection of equipment Plant engineering. Coordinating the change in specifications and designs of the plant and its equipment to optimise the performance of the project (according to the local conditions- within the current architecture).	Understanding the equipment performance in different conditions and the effects of sub-systems on final performance. Tacit knowledge of design, complex modelling and optimisation activities. Understanding underlying technologies.	Intensive R&D in technologies. Strong scientific knowledge bases. Linkages with international centres of technology and research. Design of new architectures for plants and components. Design of plants and equipment with unprecedented levels of complexity.

Pre-Project		Project			Post-Project	
Local	International	Basic	Intermediate	Advanced	Basic	Advanced
Permits engaging with customers in protected local markets	Permits participating in overseas competition	Permits the firm to manage power plant projects according to locally accepted parameters	Permits the firm to find and implement cross-project improvements, including developing a better position in the value chain and decreasing the distance from international standards	Permits the firm to improve on project management performance in response to the requirements of international competitions	Permits the firm to provide operation and maintenance services for delivered systems	Permits the firm to engage with technical problems and provide feedbacks to the design, engineering and manufacturing of systems
-Information channels with local customers -Links with limited sources of supply -Securing finance -Organisational resources to negotiate or prepare bids	-Information channels with overseas clients, data gathering on competitors, databases for project activities -Organisational arrangements to examine the feasibility of higher quality proposals and required organisational changes -Continuous search for a wider database of suppliers	-Knowledge of project activities -Knowledge of strategies, organisations, timing and costing of project activities -Processes, skills, personnel and software for project management	-Arrangements to find and discuss improvement opportunities -Systems for learning from experience in previous projects	-Arrangements to learn from competitors -Programmes to implement international guidelines for project management such as PMBOK	-Technical procedures and manuals for operation -Knowledge and skills for organising operation activities -Knowledge and experience of operation	-Arrangements to gather feedback and act upon it -Technical knowledge to analyse the system's incidents -Organisational resources and hardware for gathering technical data in plants

	Latecomer Strategic SIC	
Levels of Depth	Basic	Advanced
Brief description of the capability depth or strength	Allows for unsystematic and sporadic changes such as cross-functional improvements and changes in technological focus	Permits the firm to sense the need for and implement strategic changes in a timely manner and commit to continuous improvement
Indicative evidence in terms of the nature of underlying attributes or related activities	-Unsystematic and infrequent activities to sense the changes in the environment, including technologies, demand and the industry value chain -Partial understanding of the firm's weaknesses and strengths -Unsystematic efforts to examine alternative technology and project strategies -Lack of systematic mechanisms to look into the future	-Arrangements for sensing the changes in the environment, including technologies, demand and the industry value chain -Arrangements to analyse the firm's weaknesses and strengths -Assessing the alternative technology strategies and project strategies -Clear and shared vision -Organisational arrangements for devising and implementing long-term plans

5.4 Data gathering

The evidence for this research was gathered during two periods in Iran. The preliminary stage started in June 2008 and lasted until January 2009. The main fieldwork was carried out between August 2009 and February 2010.

As a part of the research method, the preliminary stage aimed to prepare the ground for the main fieldwork. Its objectives were twofold; firstly, to compile a historical account of developments in Iran and, in particular, technological developments in its electricity sector in order to put the study in context, find out the drivers behind decisions, explore the possible cases for study, help develop a focus in the research and build contacts for the main fieldwork; and secondly, to build an understanding of systems integration in the international context of design, engineering and building in the power plant industry, to help develop the conceptual framework, to find out about the challenges and opportunities facing latecomer systems integrators and to help interpret data during the main fieldwork. The main findings of this stage are presented in Chapter Two and Chapter Four.

Data were gathered from different sources during this stage. Two books in the Persian language on the history of Iran's electricity industry provided rich accounts of technological developments in the sector from its early days. The data was complemented by a wide range of official reports and statistical records obtained from Tavanir,
[1] either in hard copy or in an electronic format. In addition, the quest for documentary evidence on the drivers behind the fast growth of local capabilities resulted in finding two papers (in the Persian language) in the proceedings of the first Iranian Conference on Technology Management, held in 2003 in Tehran. One paper in particular contained such a detailed account of governmental policies that it encouraged the researcher to meet its author to gather more data. Although the paper's author had become a full-time advisor to the CEO of Tavanir by the time of the fieldwork, he welcomed the researcher. In terms of sectoral understanding, two textbooks, one on power plant technology and the other on modern power station practice, were the initial sources.

The knowledge obtained from these sources was later enhanced through discussions and interviews with professionals in the industry. Initially, a former head of a local client for

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[1] Iran Power Generation, Transmission and Distribution Management Company

hydro power plant projects, a former head of a state client for thermal power plant projects and a former Minister of Energy were interviewed individually. Subsequently, the strategy advisor to the CEO of Tavanir was interviewed, as indicated above. These interviews were semi-structured and lasted between one and a half and two hours. Aside from questions about systems integration in the industry, the interviews covered issues relating to the role of the government in the local sector, characteristics of the market for power plant projects in Iran, division of labour in local projects and the nature of roles of Iranian firms in local projects compared to their foreign counterparts. As these interviewees had a good knowledge of the sector in Iran, their opinion about the development of LSIC in the two case study firms was sought. The interviewees also introduced new contacts within the firms or in the industry and suggested new documentary sources of data.

Further data on systems integration in power plants, in the context of developing and developed countries, was gathered from the internet and occasionally from scholarly journals or trade magazines. Websites of leading systems integrators, in particular Siemens, GE and Alstom provided useful data. In addition to all of these sources, the researcher visited one thermal power plant in operation, and one large hydro plant under construction in Iran.

The Shahid Rajaee Combined Cycle Power Plant was constructed in two phases. The first phase was developed by Mitsubishi Heavy Industries and the second phase by Mapna, one of the case study firms. Discussions with operators about comparing the performance of the two blocks, the problems that had emerged in the operation of each block, the stories they told about the way in which each block was developed by contractors, and a tour of the plant generated valuable insights into the nature of systems integration in the industry.

The Siahbishe Pump Storage Hydro Plant was under construction by Farab, the other case study firm, in the north of Iran at the time of the visit. The underground civil structures for the turbine had already been constructed and engineers were assembling large sections of the hydro turbine. Observing the nature of activities and the scale of equipment adjusted the perceptions of the researcher. In addition, there was a chance to speak with a number of project team members through which some information was obtained about the nature of tasks on the project site. Furthermore, the researcher became familiar with the terminologies in use by the project teams and was able to relate them to the concepts of the conceptual framework. These two visits towards the end of the preliminary stage significantly helped the interpretation of data during the main fieldwork.

The main fieldwork began with Farab, followed by Mapna, after a delay. One of the interviewees in the preliminary stage introduced the researcher to the CEO of Farab. A summary of the research objectives, the scope of the fieldwork and the expected benefits for the company were presented to the CEO, based on which he assigned one of his deputy directors to support this thesis. The level of cooperation was therefore unexpectedly high in Farab. A request for data gathering was sent to the CEO of Mapna through one of the initial interviewees. The CEO referred this request to the newly-established R&D department in Mapna. After examining the research proposal, the R&D department showed an interest in supporting the research by signing a contract and assigning a helpful contact point. Although the process for getting the permission of Mapna prolonged the start of fieldwork, it proved extremely helpful later in arranging some interviews and accessing documents.

Data was gathered from the following sources through the main fieldwork period:

Interviews: a total of 51 in-depth interviews (in the Persian language) were the main instruments of data gathering at this stage. Among the 51 interviews, 28 were carried out with current or former employees of Farab, another 17 interviews were similarly performed in Mapna, three other interviewees were informants from Farab's client, two interviewees were from Mapna's client and one interviewee was a strategy consultant who had recently finished a project with Mapna. There were two reasons for arranging fewer interviews in Mapna. Evidence indicated a lower level of achievement in functional SI capability compared to Farab, requiring fewer interviews to investigate the evolution of attributes. Secondly, some learning-by-doing had occurred during the fieldwork in Farab in the sense that the researcher had obtained deeper skills to gather the relevant evidence more quickly.

The interviews were in-depth, semi-structured and were performed individually rather than in a group, each lasting between one and a half and two hours. Interviews lasted longer than planned on the occasions that interviewees were inclined to continue. Provided that the interviewee felt comfortable, interviews were recorded digitally and were transcribed in Persian, often on the same day, by the researcher. On average, the transcribing process took three times the original interviewing time. A preliminary analysis of evidence was undertaken after each interview by classifying the evidence relating to the framework and identifying the gaps, confusions and possible discrepancies to be investigated in future interviews. Texts of interviews were sent to interviewees for review. They were subsequently contacted by telephone and asked for any comments or corrections.

Based on the research design, an initial list of positions that should be interviewed (including people in functional units, project teams and senior managers) was populated for each firm. The lists were then discussed with the contact points to nominate key individuals. Often, candidates with longer experience and deeper knowledge about the questions were chosen. The lists were, however, revised during the fieldwork as a result of initial analysis of evidence or when new informants were suggested by interviewees. The interviews stopped when saturation emerged; in other words, when incremental learning was minimal because the evidence of new interviews started to be what was already known (Eisenhardt 1989) p140. The interviewees were also asked about documentary evidence necessary for the triangulation of data.

Interviewees were informed in advance, normally on the telephone, about subjects that would be covered in their interview. This strategy was adopted because, based on early experience in this research, interviewees were most often reluctant to spend time reading the questions before interviews. However, a copy of the questions was sent to the interviewees in advance of the meeting if they showed an interest in reading them. A separate list of questions was derived from the framework for each constituent part of LSIC. This list was, however, customised for each interview based on the preliminary analysis of previous interviews, and by considering the specific position of each new interviewee. Nevertheless, researcher had the whole set of questions at his disposal during every interview in case opportunities arose for gathering more data.

Interviews often started with a brief statement about the research, why the particular interviewee had been chosen and requesting permission to record the interview. This was then followed by a question about the background of the interviewee and their experience in the firm. Based on this information, new questions were sometimes added or the priority of existing questions was changed to maximise the yield of data. Often a simple question about what their unit did or the history of their unit revealed important aspects of capability development. Further questions helped the researcher investigate the level of achievement in that particular capability. The following questions were often focused on inputs, the ways that underlying attributes had been accumulated, failures and successes and comparing the performance with other firms or the past. Knowledge of systems integration in the industry, elements of the staircase models and relevant documents that had been studied before the interviews helped raise appropriate questions and comprehend the answers. Occasionally, interviewees were impressed by the familiarity of the researcher with their business, leading them to show more interest in the interview.

Two significant challenges existed during the fieldwork: identifying achievements in capability building and the dangers of retrospect sense making (Eisenhardt and Graebner 2007) in gathering data on the evolution of capabilities. The first challenge relates to the tendency of some individuals to over-represent achievements. Deploying triangulation techniques, consulting with the conceptual framework and utilising the data gathered during the preliminary stage helped overcome this challenge. For instance, if an interviewee claimed that a sophisticated technological activity had been performed, questions were asked about the division of labour between the firm and its suppliers regarding that task, the process through which the underlying attributes had been developed, the extent of success and whether the firm could perform it again if the technical specifications changed. If necessary, further enquiry was undertaken through means such as investigating the contract data or interviewing new informants.

The second challenge was the danger that individuals could, intentionally or unintentionally, present a retrospective sense making of how capabilities had evolved, providing an artificial picture instead of reflecting the uncertain and complex patterns of reality. The thesis hopes to have avoided this pitfall by consulting with other sources of evidence, collecting documentary evidence before interviews, asking clarifying questions with a focus on possible failures and asking interviewees about the implications if such perfect development had happened in reality.

Other documental sources collected from the firms included items such as long-term planning documents, annual reports, brochures and catalogues, organisational charts, procedures and instructions, project reports, lessons learned documents generated from projects, project manuals, contracts, company newsletters, and reports generated by consultants. Additionally, a number of short case studies relating to these two firms were found in the proceedings of management conferences in Iran. Attending conferences in Iran, in particular the Iranian Management Conference and the Iranian Project Management Conference, provided opportunities for further data gathering. The above documents were often in the Persian language, except for some reports generated by overseas consultants. In one of the conferences, senior vice president of Mapna made a keynote speech on technological developments in the firm. The researcher had the chance to start a fruitful discussion with him after the speech. The websites of these two firms, of their clients and of foreign leading systems integrators provided additional data about projects.

The multiple sources of data in this research were used interactively, and the same questions were asked of different interviewees in the firms or from elsewhere to ensure the triangulation of data during fieldwork (Miles and Huberman 1994). The triangulation, however, continued in the analysis and reporting phase.

5.5 Data analysis and reporting

The thesis combines analysis within each case with cross-case comparisons to enrich our understanding of the nature and evolution of LSIC. The overall analytical strategy relied on the conceptual framework and staircase models (Yin 2003). In each case, the evidence from multiple sources was classified into tables[2] (in Persian) presenting categories of inputs, transformation processes, outputs and drivers for each level of depth in the three core constituent parts of LSIC. The interviewees were coded and each paragraph in the text was numbered to provide a clear reference for data. In every cell of the tables, the evidence was ordered chronologically. Throughout this stage, the triangulation process continued. As such, additional telephone calls were made or emails were exchanged with some interviewees, and further documents were gathered from the internet to ensure the rigour of the findings. When the tables were complete, diagrams were produced depicting a historical account of developments in each firm in each constituent part of LSIC. These diagrams helped enormously in the process of writing up. During the analysis and reporting stage, iterations took place between data and theory, resulting in the emergence of themes, contradictions and new propositions (Eisenhardt and Graebner 2007). As such, the definitions were improved and the staircases of LSIC were amended. The original Persian data were translated into English as required during the writing up process.

The evidence in the case study reports is structured around the three core constituent parts of LSIC and is presented chronologically using tables, figures and quotations. On the occasions that firms had not yet achieved a specific level of depth in capabilities, the extent of developments in underlying attributes was reported. During the cross-case analysis, new tables were populated comparing the findings about achievements, inputs, transformation processes, outputs and drivers in each constituent part of LSIC across the two firms. This analysis unraveled patterns including commonalities and differences, based on which the evidence was consulted to explain the patterns. In particular, some firm-specific variations in the progress of LSIC emerged in these analyses. To understand these differences, a new round

[2] These tables were very similar to what Miles and Huberman (1994) describe as a 'thematic conceptual matrix'.

of conceptual analysis was performed and the literature of innovation studies was examined. This process is explained at length in Chapter Eight.

5.6 Summary

This chapter builds up a research design for the empirical investigation of the nature and evolution of latecomer systems integration capability (LSIC). It utilises and amends existing definitions and frameworks drawn from the relevant bodies of literature, and deploys an initial understanding of systems integration in power generation systems to develop a provisional definition of LSIC and break it down into three core constituent parts for research purposes. This conceptual framework helps dissect the main research question into a number of sub-questions.

The chapter shows how the subject of the research and the nature of the questions justify the selection of exploratory case studies to address the research objectives. It also explains the reasons for selecting Farab and Mapna, two Iranian systems integrators, as case studies. In line with the literature on capability building in the latecomer context, staircase models were developed for each constituent part of LSIC, to be used as benchmarks against empirical evidence regarding the evolutionary path of LSIC. In addition, the conceptual framework was further elaborated to indicate relevant evidence on inputs, transformation processes and outputs of capability evolution in a latecomer context.

The chapter describes the purposes of the preliminary and main fieldwork in this thesis. It explains how the main sources of evidence, including in-depth interviews with informants in the firms, their clients and the industry, company documents and visits to power plants, are to be deployed throughout the research. Finally, this chapter discusses how the thesis combines within-case and cross-case analysis to examine the evidence, identify patterns and enrich our understanding of the nature and evolution of latecomer systems integration capability.

The next two chapters present the empirical core of this thesis based on an in-depth account of developments of micro-level attributes, including people, knowledge, processes and structures, underlying each core constituent part of LSIC. This includes an analysis of the changes in products, systems and capability outcomes in each of the two case study firms, namely Farab and Mapna. The aim is to interpret the achievements in the capability building journey and develop an understanding of LSIC evolution in each case.

6. Chapter Six: Farab, A case of strong functional SI capability

This chapter investigates Farab [1] as one of the case studies in this research. Farab was established by Iran's Ministry of Energy in 1992 as a project management company to manage the construction of hydro power plants in Iran. The firm grew over time and entered into international hydro power plant markets while simultaneously diversifying into local markets for other energy projects. As of December 2009, about 86 percent of Iran's hydro power generation capacity was built and delivered by Farab (Tavanir 2009). This chapter aims to present evidence and find answers to questions about the nature and evolution of latecomer systems integration capability (LSIC). In particular, it investigates questions about the composition of LSIC, the level or depth of its constituent parts, how LSIC has evolved over time and the motivations or driving forces behind its evolution.

The content of this chapter is based on data gathered through in-depth interviews with current and former key individuals in Farab, in-depth interviews with informants in a local client organisation, visiting one project site and collecting relevant documents from the firm. The presented evidence shows that Farab initially offered low-cost project management services but gradually accumulated stronger LSI capabilities, including the design of complex hydro turbines. It also indicates how this course of development was affected by external forces and the firm's own initiatives. Based on our conceptual framework, the firm has passed the basic level in all three constituent parts of LSIC, has reached or is nearly reaching the intermediate level in most of the parts, and is currently developing the advanced level in some areas.

The chapter is organised into three sections. It starts with an introduction that describes the wider context at the time of the establishment of Farab and highlights elements that were significant in the course of capability evolution. It also presents a brief chronological account of developments in the firm as a point of reference for the subsequent sections. The chapter continues with a long section presenting detailed evidence on the evolution of each constituent part of LSIC. The final section summarises the chapter and discusses several findings.

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[1] http://www.farab.com

6.1 Context of establishment

Investigating the origins of Farab requires a wider look at the evolution in the system of executing development projects in Iran's electricity sector and its status at the time Farab was established. While a full depiction of that evolution could be a separate line of inquiry, we will illustrate a brief historical account with a focus on the hydro power electricity generation sub-sector for the purposes of this thesis.

From 1904 to 1979

During this period, development projects were performed by international systems integrators under turn-key schemes. Based on official statistics (MOE 2004), around 4 percent of products and services required for projects were sourced from local suppliers in 1979. During this period, seven medium-sized and large hydro power plants were built with a total capacity of 1070 MWs.

From 1979 to 1989

Amid the unrest leading to the Islamic Revolution in Iran, contractors and some owners of projects left the country. When the new government was established, most previous contractors could not resume their work in the new revolutionary context. A major challenge in Iran's Ministry of Energy[2] (MOE) was to devise a new system for projects. As a result, state-owned companies were created as substitutes for previous firms in the consulting, engineering and erection/installation of projects.

In parallel, investments were made to manufacture some equipment and parts. These initiatives were driven by import-substitution strategies that had started before the Revolution and continued more rigorously after that. During this period, SANIR Company was created as a joint venture between the Ministry of Energy and the Industrial Development Organisation of Iran for the engineering and installation of hydro power plants. In 1984, the company was renamed Farab, and its scope of activities was changed to encompass manufacturing hydro turbines and hydro pumps. Farab was however inactive until 1992.

By 1989, local capability had developed to a level that could potentially supply around 80 percent of the equipment required for projects (speech by Eng. Zangane at the First

[2] This Ministry is responsible for the development and management of the water and electricity sector in Iran. Governmental responsibilities regarding the provision of fossil fuels and generating electricity from nuclear technologies are excluded from its scope of activities.

International Electricity Exhibition of Iran, 2000).[3] However, international systems integrators responsible for the management of projects (which were known as EPC contractors or General Contractors in Iran at the time) were reluctant to use the local capabilities. They preferred to source equipment from their own suppliers to reduce the risks.

This period was later described as the maturity of local content development (speech by Eng. Zangane at the First International Electricity Exhibition of Iran, 2000). During these ten years, just two medium-sized and large hydro power plants were built with a total capacity of 125 MWs under turn-key schemes. The eight-year war with Iraq significantly slowed down developments in this period.

From 1989 onwards

The challenges experienced in the previous stage nurtured the idea that developing local manufacturing capabilities was not enough. The new thesis was to develop local project management companies capable of making wise decisions (in terms of quality and price) about the choice of suppliers. Cheaper energy and cheaper local labour should logically result in manufacturing cheaper local equipment. Provided that the quality was in a satisfactory range, the local project management company would choose local content over importing from expensive suppliers. This period was later described as becoming intelligent in the development of local capabilities (speech by Eng. Zangane at the First International Electricity Exhibition of Iran, 2000).

In line with this general trend, it was contended that Farab turbines would not be easily used in projects by foreign contractors. The mission of Farab was therefore revised in 1992 to become a general contractor for hydro power plants. The main objectives in establishing Farab were to provide a cheaper solution for public investments in power generation, to support the growth of feasible local content and to facilitate technology transfer to local manufacturers (Refan 2003). Economic analyses showed that 75-80 percent of costs in power plant projects were spent on equipment and the rest was spent on engineering, project management and installation. A local contractor should at least reduce the costs of the latter tasks.

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[3] Mr. Zangane was the Minister for Iran's Ministry of Energy from 1988 to 1996.

6.2 Developments up to 2002, learning the basics

There were doubts in the Iranian industrial sector about establishing and operating a general contractor in such a sophisticated industry given the lack of previous experience. The first years were spent on internal discussions about how to manage a hydro power plant project. There was no local systems integrator at the time to learn from and international examples had evolved over a long time so that their current status appeared incomprehensible for the senior management team. Decisions on the firm's structure, make/buy pattern and project execution were made after intensive discussions.

After two years of making initial decisions on structure and make/buy choices, Farab was invited by the Ministry of Energy to participate in an international competition to expand the Shahid Abbaspour plant (Karun I), although Farab had no project reference. Farab won the project by proposing the lowest price in the competition. After Karun I was started in 1995, three new projects, namely Karun III, Masjed Soleyman and Karkhe were awarded to Farab by the Ministry of Energy on an offer basis. Karun III was originally granted to ABB on the condition that ABB finance the project. The inability of ABB to secure the financing led to Farab taking over the project, proposing half the price of ABB.[4] The Masjed Soleyman project was supposed to be financed by a Japanese institute, but it withdrew under pressure from the United States. After the experience of Karun III and considering the possible reluctance of international institutes to finance projects in Iran, Masjed Soleyman and later Karkhe were granted to Farab. Farab had to start four large hydro power projects almost simultaneously in 1995.

In the period from 1995 to 2002, Farab was heavily engaged with organising for these four projects and learning the capabilities to carry them out. The former Head of the Planning and Project Control Department describes the period:

> "In the early years, we were following the bureaucratic procedures of project finance, teaming up with international suppliers, bringing them to Iran and matching them with local suppliers for technology transfer. Then we focused on manufacturing the equipment and erecting the plants. Farab could not think about anything else, even market development."

[4] US$ 400m in comparison with 770m offered by ABB.

The order of learning efforts in this quote reflects the order of activities in a typical hydro power project. Approaching the end of this period, three new projects were secured, namely Karun IV, Tose Masjed Soleyman and Gotvand with a total capacity of 3000 MWs.

Contract signed	Project Name	Capacity (MWs)	Turbine	Location
Before 1995	Karkhe	3*133	Francis[5]	Iran
	Karun I	4*250	Francis	Iran
	Masjed Sol.	4*250	Francis	Iran
	Karun III	8*250	Francis	Iran
Between 1995 and 2002	Tose Masjed Sol	4*250	Francis	Iran
	Karun IV	4*250	Francis	Iran
	Gotvand	4*250	Francis	Iran

Table 6-1: List of secured projects from 1995 to 2002

6.3 From 2002 onwards, looking for new markets

In 2002, the first unit of Karkhe power plant finished its trial operation phase and was handed over to the client as the first Iranian-built hydro power plant. The remaining units of Karkhe, Karun I, and Masjed Soleyman were delivered between 2002 and the end of 2003, leading to an ease of pressures on the firm's resources. A series of discussion meetings was then organised in the firm to reflect on the projects' experience. These sessions lasted for two years, and at the end, a list of 18 improvements was prepared. One of the outcomes was to internalise erection and installation activities. A new division was created in 2006[6] for this purpose. In 2002, Farab had 380 full-time personnel in addition to temporary individuals who were employed on projects. The delivery of the first projects considerably increased the self-confidence of the organization, as a high-ranking manager put it:

> "We had gone through all the phases of complex projects for the first time and we felt strongly that we could embark upon other EPC projects."

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[5] Hydro turbines have different technologies mainly based on the concept that water energy is transformed into mechanical movement. This concept largely depends on how the water enters into the turbine and what the shape of the turbine runners looks like. The most common technologies are Francis, Kaplan and Pelton (Source: A Technical Guide to Hydro Power Plants, Farab, 2004).

[6] The reasons behind this decision will be discussed in the following sections.

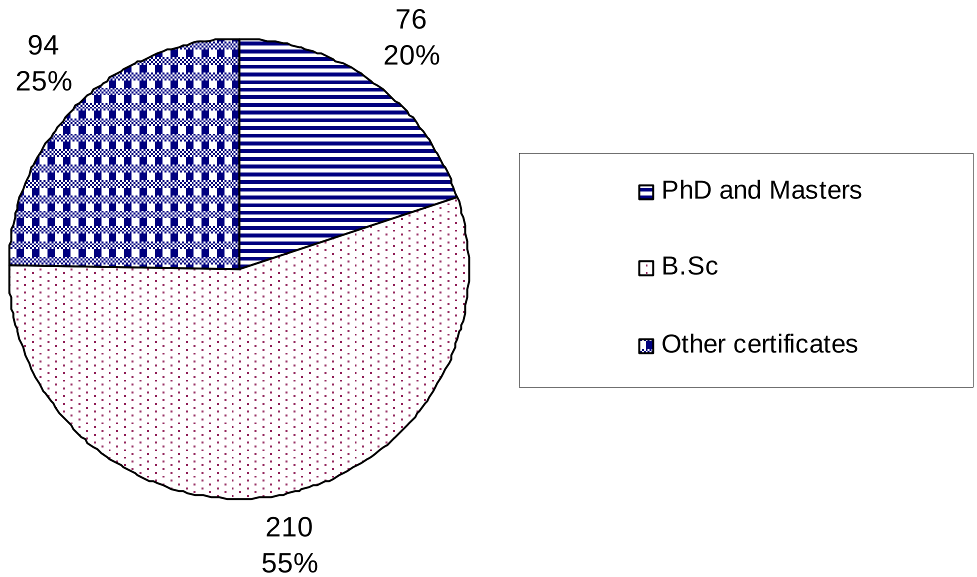

Figure 6-1: Number of Farab personnel according to their certificates as of 2003 (Farab Annual Report).

The analysis of Farab showed that the outlook for new hydro power projects in Iran was not very promising, due to both the remaining potential sites and the high costs of hydro plants compared to fossil fuel alternatives to respond to the increasing demand for electricity in the country. Meanwhile, a number of local competitors had arisen as a result of sub-contracting for Farab in previous projects or due to assimilation of Farab's model. The firm decided to enter into overseas markets for hydro plants and into the local market for energy projects. The Head of the Engineering Department says:

> "We had not thought about competing in international markets until 2002. In 2002, we recognised that the local market was not promising, but Farab had 400 qualified personnel for engineering and the management of projects. We wanted to use this potential. In retrospect, if the local demand had remained promising we would not have considered overseas markets."

As the following sections show, this human resource base of Farab was chosen from among fresh university graduates and people with experience in other local industrial projects. They went through formal training programmes after employment and learned from working with foreign supervisors during the projects.

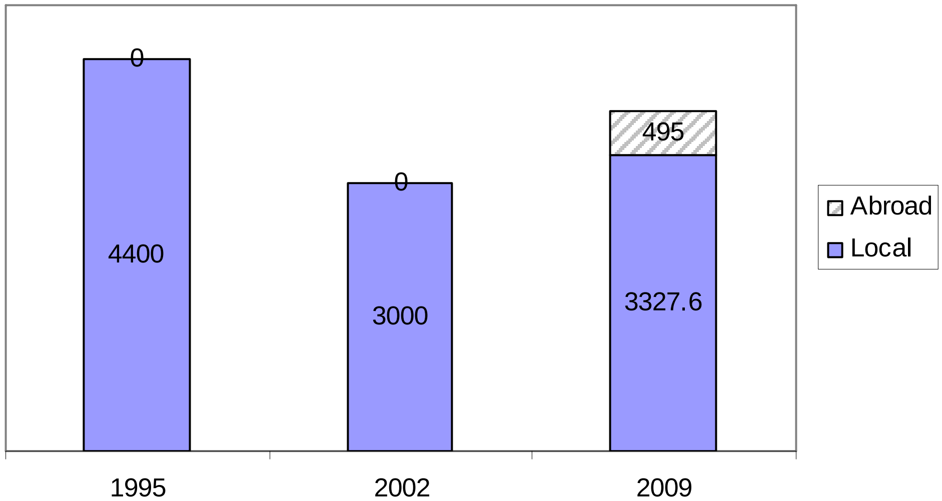

Figure 6-2: Total volume (in MWs) of new hydro projects secured in each period (compiled from Farab Annual Reports).

Farab created a market development unit in 2004 and started to actively seek new projects. Since 2002, 15 projects with a total capacity of 3327.6 MWs have been secured in the local hydro power market and, Farab has started five overseas projects with a total capacity of 495MWs (Annual Report 2008), in addition to some projects pending financing and signing of contracts. The new round of embargos from 2005 has generally affected Iran's exports. For Farab, in particular, working with international financial institutions is becoming increasingly difficult, suppliers have changed their terms and conditions and doors to a number of overseas markets have been recently closed to Iranian contractors.[7]

Project Name	Capacity	Turbine	Location
Siah Bisheh	4*250	Pump-Turbine	Iran
Saymareh	3*160	Francis	Iran
Sangtude II	2*110	Kaplan	Tajikistan
TANA	26	Francis	Kenya
Oma Uya	150	Francis	Sri Lanka
Kuhrang	3*13	Francis	Iran
Lavarak	2*23.5	Francis	Iran
Shahid Rajaee	3*4.5	Francis	Iran
Khoda Afarin	2*51	Francis	Iran
Rudbar e Lorestan	Not specified	Pump-turbine	Iran
Zayanderud	2*4.25	Francis	Iran
Kavar	2*6.1	Francis	Iran
Pakistan	130	Francis	Pakistan
Bakhtiari	1500	Francis	Iran

[7] There are cases in which Farab had to withdraw from competitions due to political pressure, including a gas-fired power plant in Kenya, a competition in Morocco and Sangtude I hydro plant project in Tajikistan.

Sardasht	130	Francis	Iran
Azad	10	Francis	Iran
Dez	20	Francis	Iran
Gavshan	4.6	Francis	Iran

Table 6-2: Key hydro projects in this period

In terms of other energy projects, Farab has secured a number of BOO[8] contracts in gas-fired, combined cycle, geothermal and wind power plants[9] with a total capacity of 4532 MWs (Annual Report 2008). The firm has also diversified into oil and gas projects in Iran by securing four utility projects[10] with a total capacity of 473Mws and four contracts to develop oil and gas fields (Annual Report 2008). Attempts to secure projects in rail transport have been unsuccessful so far but the firm continues to leverage its systems integration capabilities to enter into new markets. In 2009, Farab had 686 full-time personnel.

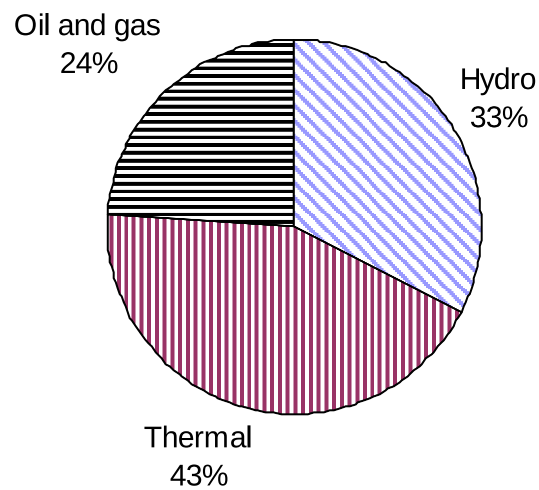

Figure 6-3: Share of active project values in various markets as of 2009 (Farab Annual Report).

6.4 The evolution of LSIC

6.4.1 Latecomer functional SI capability

Engineering and design[11]

[8] =Build Operate Own strategy in the execution of infrastructure projects.

[9] Farab and Mapna were both established by the Ministry of Energy. From the outset, they drew a line between their respective business fields so that Farab concentrates on hydro power projects and Mapna on thermal power projects. Later they revised this rule to merely include projects that are financed by the government.

[10] Utility plants are relatively smaller electricity power plants built in refineries and petrochemical complexes to primarily deliver electricity for their processes.

[11] Engineering and design activities in a power plant can be classified into several interrelated levels. The conceptual design of a hydro power plant specifies the overall characteristics of the plant, including the number of power units, their output, the technology of the turbine, key parameters of core equipment and the layout of the power plant. This level of design is usually performed by professional consultants or engineering offices within the client organisation. Basic and detailed engineering of hydro plants, however, largely deals with the choosing, specifying, scaling or design of the equipment or systems to realise the conceptual design. In this context, 'design review' is checking the designs from two general aspects: (1) congruence with the conceptual design of a plant and the criteria of a balanced operation, and (2) the possibility of delivering what the designs promise.

The lack of previous experience in the country necessitated the use of foreign firms in the development of functional SI capability. Also, young engineers and technicians were hired by Farab from local universities and institutions, and some were hired with experience of working in other local projects such as the construction of steel plants. Farab organised its engineering department into three functional sub-units: mechanical, electrical and control. Engineers were employed from among fresh graduates or those with experience in other local industrial projects. In the first four projects, the client expected Farab to learn the engineering from international firms. Farab used two separate arrangements for this purpose.

For Karun I and Karun III, a five-year contract was signed with SMEC Co. from Australia. SMEC agreed to supply one technical manager in each of the mechanical, electrical, and control areas and one for overall engineering tasks, four experienced engineers in total.[12] In this arrangement, a project-based structure was used in which SMEC had the overall responsibility of engineering in each area and organised Farab's engineering team. Local engineers were supervised by the foreign engineers for learning the 'design review' of core equipment and engineering of non-core equipment.

In the Karkheh and Masjed Soleyman projects, a matrix structure was used in which Farab was responsible for engineering[13] and employed three foreign professionals in each of the areas mentioned above: one from Hydro Quebec RSW Co., one from North West China Co. and one from Tata Co. The foreign engineers worked under the management of Farab and cooperated with their local colleagues.

When SMEC's contract ended, the engineering activities of Karun I and Karun III were not yet finished. Nevertheless, the local team had built a level of confidence to continue without help. The other nine foreign engineers, employed in the Karkheh and Masjed Soleyman projects, were also released gradually. By the year 2001, no foreign engineer was working in Farab.

The focus of these two learning mechanisms was on building knowledge about plant design, plant performance, interfaces among sub-systems and engineering of non-core equipment. The manager of TANA project in Kenya, a former member of the Engineering Department, says:

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[12] According to this arrangement, every foreign engineer supervised 20 local engineers.
[13] The experience of organising engineers in a project structure in the former arrangement had caused several problems.

> "In those days we were focused on learning the interfaces [among sub-systems]. When I was reviewing a document, I was not sure whether I should pass it to the mechanical and electrical teams or not. When we mastered this knowledge on the interfaces there was always a risk of forgetting the workflow. Implementing ISO 9001 standard helped us systematise the work."

To understand the engineering of core equipment in projects, Farab arranged a different plan. For hydro turbines, a professional designer who was also a university professor was invited to stay in Iran for nine months, teaching Farab engineers about hydro turbine design, how it works and what affects its reliable performance. After initial theoretical trainings, he and three local engineers travelled to China where they resided in the turbine laboratory of HEC (the systems integrator of turbines in two of the projects) for three months to gain practical experience in prototyping, testing and inspecting the manufacturing process. The team transferred the knowledge to their colleagues on their return to Iran. One of the engineers who were sent to China is currently Head of the Mechanical Engineering Unit in Farab. He says:

> "Training was at a very good time. It formed a basis that allowed us to interact with our turbine contractors and to review their engineering documents."

As regards the generator, two engineers resided in the Siemens factory in Brazil for six months where they learned about the manufacturing process. One of the engineers was eventually transferred to the Market Development Department and the other one left Farab.

As has already been mentioned, Farab took over the engineering activities halfway through the first four projects. The engineering capabilities have evolved through time as the firm has engaged with an increasing number of projects and has embarked on several mechanisms of capability building. Every hydro power plant has its own unique design that might cause new challenges for engineers, creating a situation for continuous expansion in knowledge. In particular, learning opportunities are high in projects with new turbine technologies. The majority of plants delivered by the firm have Francis-type turbines but Farab is currently experimenting with pump-turbines and Kaplan-type turbines in the Siahbishe and Sangtude II projects respectively. Training programs have been arranged to extend the previous knowledge of the behaviour of new-to-the-firm technologies.

Farab[14] has accumulated knowledge through its projects on the operation of power plants, the differences between actual performance and the design promise of turbines, the 'executability' of plant designs, and the actual costs of sourcing and installing equipment.[15] These elements of knowledge form the basis of energy calculation, which is a major task in plant design. The firm has used this capability in some projects and several cases confirm that Farab's recalculations are more accurate than the initial design by consultants. For instance in a project in the north of Iran, recalculations by Farab showed the infeasibility of the initial design.[16] This review resulted in the cancellation of the project by the client.

In addition to learning that happens through carrying out projects, the commitment of the firm to optimising initial designs has often led to innovative technological activities and resulted in a better understanding of power plant behaviour. In all of the first four projects, some optimisations were carried out in non-core equipment in order to primarily reduce project costs. For instance, the diversion gates of the Karun III project were replaced by an innovative cheaper local design. Similarly, the initial design of the tailrace in the Masjed Soleyman project was exceptionally long and would increase the operation and maintenance costs in the future. Farab added a new gate to the end of the turbine section which was carefully designed not to affect the turbine's performance in normal conditions. Although these innovative activities took place in non-core equipment, their possible effects on turbine performance ought to be analysed to convince the client.

Feedback from the later stages of projects[17] appears to have also improved engineering capabilities in Farab. For instance, difficulties in the installation of equipment in projects have often stimulated improvements in project engineering or the design of equipment. Over time, the firm has improved its organisational arrangements for capturing and implementing such feedback. For instance, a Quality Control Department has been established to analyse defects in each phase of a project and feed them back to the engineers. Similarly, the Engineering Department has recently started to send out its engineers to each project site for systematic gathering of feedback.

One particularly effective feedback mechanism is learning from problems or possible failures during the operation of plants. The Engineering Department periodically gathers reports of

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[14] Each hydro plant project has a trial-run period during which the plant is operated by the systems integrator to find and fix any possible defects.
[15] Using unrealistic equipment costs can result in unrealistic energy calculations and weak plant design.
[16] This project was called Stor Shahriar.
[17] Namely, manufacturing of core equipment, erection and installation of systems and trial operation of the plant.

incidents in power plants all over the world in order to increase its technological understanding and prevent the same incidents in ongoing projects or, if necessary, to modify delivered plants. Incidents may also happen in Farab's plants during both the trial-operation and post-delivery periods. The policy of the firm is to engage with such incidents for learning.[18]

The one-year trial operation of plants is the period in which possible problems, arising from various project activities, may surface to be fixed before final delivery. In some of the initial projects, serious incidents occurred related to core equipment that was designed by leading suppliers. In retrospect, Farab's engineers analogise those incidents to a university, reflecting the plethora of learning opportunities they offered. For instance, the butterfly valve cracked in one project after six months of operation. An analysis by Farab's Engineering Department revealed the design weakness, and modifications were implemented. A critical incident was related to turbine blades designed and manufactured by Siemens. Dealing with this incident was a landmark in the development of latecomer functional SI capability in Farab.

Turbine failure in the Masjed Soleyman project

This plant has a large Francis-type turbine with a four and a half meter (in diameter) runner and a seven meter spiral way. During the trial-operation period, 11 cracks appeared on the turbine blades. Initial investigations by Siemens put the blame on bad operation; however, Farab believed it to be caused by a design weakness. In order to settle the dispute, Farab's engineers had to analyse the hydraulic behaviour of the turbine, in which they had no experience. While the usual design practice is to build a model on 1/12 scale, Farab decided to build a full-scale model for better results. The engineers needed to measure the geometry and profile of several parts of the plant because Siemens refused to provide the relevant details. A research centre was found in Iran that could measure those profiles. The resulting simulation model was so complex that it required a networked computing capacity. This capacity was found in a local university. By running the model and analysing the results, engineers could identify the design weakness. When Siemens suggested modifications to resolve the matter, they were tested again on the model and proven to be ineffective. Siemens ignored the comments and new cracks appeared within 200 hours of operation of the modified turbine, exactly as had been predicted by Farab. The Head of the Engineering Department recalls the case:

[18] So far, two incidents have been recorded during post-delivery operation of Farab's plants. Further investigations by the client have proven the roots to be careless operation in both cases.

> "We have bright engineers with top qualifications in Farab. They are interested in research. In the Masjed Soleyman project, they proposed that they could identify the root [of the problem] and we supported them. They went out and found specialised resources in Iran to carry out the related activities. They found a group that could measure the geometry accurately enough for us ... [Our engineers] had to model the turbine for which they required software and we bought it for them ... then something else was required and so we went along this process step-by-step. Our engineers naturally discovered through this work the process that is required for designing a large turbine."

The capability for modelling and understanding the hydraulic behaviour of turbines was used in subsequent projects to examine the claims of turbine designers, resulting in enhancement of the capability. This capability is also used in preparing better technical bids or offers. In a particular rehabilitation contest in Africa, the operator of the existing plant had complained about problems that sediments created in the turbine. Farab's analysis revealed a major design weakness in the plant. The technical proposal prepared based on this understanding was highly praised by the client.[19]

Innovations in Sangtude II project

Sangtude II was the first project of Farab in an overseas market starting from 2006. The project has affected different aspects of systems integration capability in Farab. In this section, we will focus on the aspects related to latecomer functional SI capability.

The Sangtude II plant was designed by a Russian engineering firm and has been co-financed by the Iranian and Tajik governments, each having 50 percent of the shares. Project tasks started after a two-year delay during which equipment prices had risen. Farab rechecked the feasibility of the project for the clients under the new circumstances and it was revealed that the suggested energy output would be realised only in rare circumstances. Farab proposed a change in the size of the turbine to increase its efficiency and to decrease the diameter of the runner from 9.4 meters to 8.5 meters.[20] Following this suggestion, construction work could reduce considerably and other hydro mechanical equipment would become smaller in size. These changes would significantly decrease the project costs. Furthermore, only one or two turbine designers in the world could cope with the high complexity of the initial turbine. The

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[19] One point needs elaboration. Systems integrators of hydro plants do not often check the designs of leading turbine designers from a performance perspective. Designers guarantee their turbine designs. Technical failures during the trial-operation period of past projects in Farab, however, have prolonged projects leading to long delays in the release of Farab's bonds. On the other hand, the local client often puts the blame on Farab when a failure occurs even if it is caused by a leading designer. Farab hopes to reduce these risks by checking the designs.

[20] As the runner diameter increases, the design becomes more complex. Even leading systems integrators might experience unexpected problems in designing very large turbines.

new technical specifications, however, allowed a Chinese designer to become qualified, leading to further reductions in project costs.

Additionally, this turbine was a Kaplan-type turbine, with which Farab had no prior experience. The designer had suggested large emergency gates and servomotors for controlling the turbine in the initial design. Farab leveraged on the potential of Kaplan technology in freely passing through excess water flow, and suggested a lower-cost alternative for turbine control. This suggestion was able to save around 20 million Euros in costs. It was initially opposed by the owner's consultant, the Austrian firm VATech, because nobody had attempted it anywhere before, but the opposition was removed after further investigation. This was a new concept for controlling a Kaplan turbine which was estimated to cut between ten and 20 percent of costs where it was feasible for implementation. Farab's engineers believe that if they had not been under pressure to cut costs they would have not thought of this new-to-the-world concept for turbine control.

Turbine design

The turbine is arguably the most complex system in a hydro plant and significantly affects the economic performance of the plant. The cost of turbine design in large plants is normally less than half a percent of the total project costs. Farab's initial perception was that this relatively low-cost activity could be outsourced on competitive terms. Managing an increasing number of projects, however, indicated the significant effects of this task on project costs and time, as a weakness in design can cause several months of rework. The new embargos imposed by the USA have also increased the costs of working with leading designers.

In 2002, Farab proposed to the local client that the firm would invest in building its turbine design capabilities if the client promised a set of contracts for 20 small and medium-sized hydro turbines.[21] Despite the fact that the client was unable to finance the contracts at that time, Farab created a design division in 2003. Two engineers who had previously been involved with the analysis of the failure in the Masjed Soleyman project moved to this new division and were joined by a new engineer with experience in designing and manufacturing large hydro pumps. Large hydro pumps are similar in design and performance to small hydro turbines. In the absence of local support,[22] the firm decided to finance a small plant and

[21] This package is known as the Kohkeloye Boyer Ahmad Zone.
[22] The local client compared Farab with Mapna on several occasions and complained about Farab not owning a turbine manufacturing factory. Farab justified its decision on the grounds of the economic infeasibility of building the factory without

design its turbine to push its capabilities forward and improve the image of the firm. This project was named Mehrian, and comprises two 1.5 MWs turbines with an 0.8 meter diameter and 89 percent efficiency.

Hydraulic turbines have to be designed specifically for each project site according to its geographical characteristics, although the experience of previous designs helps the designer. Different areas of knowledge are required for the design of hydro turbines. Knowledge of turbine behaviour in general and, in particular, knowledge of possible harmful behaviours, the behaviour of water around the turbine and the hydraulic design of the turbine are critical for the design. Creativity is also required to find solutions for challenges that arise during the design process. Farab had developed some elements of the first two building blocks of design knowledge during the design review, manufacturing, installation and operation of previous turbines. This knowledge was also enhanced by regular monitoring of incidents in plants all over the world.

However, hydraulic design is an iterative process of design, modelling, analysing behaviour and improving upon the initial design to reach a satisfactory point. Farab had already built some capabilities in modelling and analysing, and had guessed at the nature of the iterative process during analysis of the turbine failure. Although there are international standards for some aspects of turbine design, the equations for hydraulic design are unique in each designer firm and are built over time. The Head of the Design Team in Farab says:

> "Every hydro power plant, like a human individual, has a unique personality and it is impossible to copy one project's design for another. When you look at designers' catalogues, you can see the unique personality written alongside each turbine ... the most critical part is the shape of the turbine blades ... for a long time we had the question in our minds about why the shape of blades becomes so different from one project to another and why they have such a unique 3D shape in each project ... we contemplated several designs of a single firm to guess the equations behind the designs ... once we perfected this with different designs of one leading firm we tried to see whether it worked for designs of another leading firm or not ... we realised that every leading firm has its own design fashion. There is no single design for a particular turbine ... through time we developed our repository of equations and built a computer application to help us in design. After getting an initial design from our software for each turbine, we start a painful iterative process of computer modelling and improving the design to correct its harmful behaviours. Experience is needed to guess the behavioural problems and to solve them."

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having a minimum demand in the local market. As these discussions repeated over time, Farab realised that the client and the Ministry of Energy interpreted Farab's justifications as an excuse to cover its inability. Farab wanted to defend its capabilities through investing in its own plant and designing a turbine for it.

The first Farab turbine (a small hydro turbine with 89 percent efficiency) was still waiting to be manufactured at the time of research. There will be no certainty over the accuracy of Farab's design knowledge until the turbine starts working in the plant. To increase the firm's confidence in the design process, Farab undertook designing a large hydro turbine in one of its project while it was simultaneously being designed by a leading designer in 2008. Farab's design promises a 95 percent efficiency level. Due to the high manufacturing costs and the sensitivity of clients to turbine efficiency, the design of large turbines is often validated through prototyping and laboratory testing. At the time of research, a contract was signed with a laboratory to build and test Farab's prototype. If the test confirms Farab's claims, the self-confidence in the design team will increase considerably. The Head of Turbine Design says:

> "It will show that our claims in small turbines are also valid ... now we have a good understanding of turbines, we know how they work and how changes in one part affect the turbine's performance, but we need to design more projects and test them to accumulate experience ... our difference with Siemens is that we have designed only two turbines but Siemens has several hundreds of proven designs and when it receives a new order it looks in its repository to find a closely similar design to start with ... we need more design projects."

Another event in 2009 appears to have increased the confidence of Farab in its design knowledge. Siemens is the turbine designer in the Tose Masjed Soleyman and Gotvand projects. It has promised to design a turbine with 96.2 percent efficiency. However, the prototype did not validate the design claims and Siemens has demanded more time for redesign. The Head of Farab's Engineering Department says:

> "This was a golden experience for us to know that even a leading firm can fail in moving towards higher levels of turbine efficiency. If we are aiming to design high-efficiency turbines, despite all the efforts that our team puts into the process, the design will not be 100 percent accurate. We should build models, test them and accept the related mistakes."

At the time of writing this chapter, the researcher was informed that the local client has finally signed the contracts for 20 small and medium-sized turbines that were mentioned in the opening paragraphs of this section. Farab was working with one leading designer to establish a joint design office for this programme.

In addition to the evidence on successes and failures presented throughout this section, the records indicate that Farab's technical proposal was evaluated as the best or second-best in 90 percent of overseas competitions. Another indication of developments in the design and engineering capabilities of Farab is reflected in the evolution of the nature of its relationships with leading designers. The Head of Mechanical Unit in the Engineering Department puts it this way:

> "In some previous projects, leading firms ignored our comments but time proved that we were right. Over the past years, we have faced several problems during the trial-run of plants and we have learned from them. Our engineers have become stronger. Now, [leading firms] respect our comments. Even in the most recent cases, they ask us to check their design before it goes for prototyping."

The same Engineering Department is also involved in engineering non-hydro power generation projects such as gas, combined cycle, wind and geothermal plants. The experience and capabilities in hydro power projects form the basis for engineering the new projects, but this base is often expanded through training programmes. Although Farab has recently entered into the market for gas power plants, the firm has used its modelling and simulating experience to improve the non-core sections of gas turbines. For instance, the shape of the air intake equipment in a project has been changed to reduce the project costs. Modelling and simulating capability have helped Farab to convince the turbine manufacturer that the changes will not reduce the turbine's efficiency. Mapna, the other firm in our study, has not embarked upon such improvements despite being in this business for a very long time.

Manufacturing

Farab's initial aim was to increase the share of local content in projects. The firm had to spend organisational resources (time, money and people) to match leading suppliers with Iranian counterparts and coordinate knowledge transfer. The leading suppliers often provided the knowledge for manufacturing processes and supervised Iranian suppliers throughout the process. Additionally, they transferred quality control systems to Iranian firms to ensure components are made according to high standards.

Farab acquired parts of its manufacturing and quality control knowledge through the coordination of these arrangements. In 2000, the firm established an independent division to manage the manufacturing of equipment in the local chain. Engineers in this division had on average ten years of experience in manufacturing heavy equipment (Farab Annual Report, 2000). At the outset, equipment such as the turbine was contracted out to a single local manufacturer. This practice created delays and cost overruns in some cases. The single contract was therefore broken down into a number of smaller packages to be contracted out to several smaller contractors as Farab accumulated more manufacturing knowledge and gained a realistic evaluation of local capabilities. The new division breaks down the turbine into parts, and coordinates the manufacturing process with several contractors to ensure that the final systems will deliver the expected performance. The Head of Manufacturing Division says:

> "We do not necessarily need a manufacturing facility. We have broken down the turbine into components that could be manufactured in several places and we make sure that each component is made to the expected quality. Our strategy is to retain overall manufacturing knowledge and divide the work between several factories depending on the conditions and economic benefits."

Farab has no manufacturing facility at the moment. However, the division has managed the manufacturing of turbines[23] and several other types of heavy equipment for seven projects[24] so far. Recently, Farab has been asked to give its price for supplying some systems to a leading systems integrator, indicating the development of capabilities in Farab.

Installation

Construction of large hydro plants is a long process. Manufactured or semi-manufactured components are normally delivered to the project site and skilled technicians and engineers assemble the equipment and connect it to the interfaces. Initially the strategy of Farab was to outsource the erection and installation tasks to local contractors. The leading suppliers of equipment normally provided instructions and experienced supervisors to the local contractors for this purpose. As a result of discussion meetings after the first four projects, Farab decided to take over these tasks by establishing a new division for erection, maintenance and operation in 2006. This decision was driven primarily by concerns about the weakening of Farab's advantage in the local market.

Engineers and technicians involved in the erection of previous projects were transferred to the newly-established division. The division had also collected instructions and drawings from local contractors and enhanced its capability by learning from interactions with foreign supervisors in ongoing projects. In the first project completed by this division, the erection and installation costs reduced by 30 percent compared to the previous records. Erection times also reduced considerably, in some cases from 24 months to six months for a system.

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[23] Due to reasons explained in the previous section, turbine designers preferred to manufacture turbine blades in their own factories abroad. However, turbine runners were in some cases manufactured in Iran.

[24] These projects were Tose Masjed Soleyman, Gotvand, Karun IV, Siahbishe and Seymareh.

However, Farab still depends on leading supervisors for the erection and installation of core equipment. The Head of this division says:

> "We trusted our local contractors to learn this knowledge, but we still need leading supervisors for 20 percent of tasks. The team with experience of assembling and installing five generators from one manufacturer still faces difficulties in installing the sixth one. However, if time and costs were not important we would learn the remaining 20 percent by trial and error ... This weakness goes back to Farab's initial strategy. We did not aim to carry out erection and installation in-house and did not invest in learning it properly. We wrongfully thought our local contractors had learned it."

Analysis and interpretation

Lack of previous experience in the local industry and the insufficiency of academic training for the projects necessitated the use of foreign help in the development of functional SI capability. Farab initially learned design review and engineering of non-core equipment by hiring technical supervisory services from leading firms. In addition, a foreign professional turbine designer conducted training courses for Farab's engineers in Iran and then travelled with some of them to a turbine laboratory in China in order to teach practical issues about turbine behaviour. Understanding the behaviour of hydro plants, as a major building block of functional SI capability, was enhanced through dealing with the unique design of every project and working with various hydro turbine technologies. Feedback from the later stages of projects, such as manufacturing and the trial operation of the plant, have also refined Farab's engineering capabilities.

Even the initial engineering capabilities were deployed innovatively by Farab to improve upon plant design and optimise the choice or design of non-core equipment to fit the local conditions in projects. Analysing technical failures during the operation of plants led to the accumulation of a deeper knowledge about turbine behaviour and gradual build-up of attributes for modelling and analysing the system. The firm also discovered the process of turbine design through these modelling and analysing attempts. As the understanding of system behaviour improved, smaller-scale improvements in non-core equipment were combined with major improvements in core equipment. The accumulation of deeper attributes also permitted the formulation of better technical proposals.

Although some attributes required for turbine design were created through the analysis of failures, lack of orders from the local client hampered the further development of capability for around five years. Eventually, Farab invested in a small power plant and started to design its turbine in order to prove the depth of its capabilities to the local client. Some of the other necessary attributes for turbine design were acquired from local research centres and a local firm in the business of manufacturing large hydro pumps (a fairly similar technological product to small hydro turbines). Curiosity and the personal aspirations of engineers were critical in discovering the hydraulic equations for turbine design and solving the numerous challenges that occurred throughout the process. The equations were heuristically found by engineers through contemplating the unique design styles of some of the leading firms. Confidence in this conjectural knowledge was gradually improved by observing the design failures of leading systems integrators.

The first turbine designed by Farab had a lower efficiency level compared to the most advanced designs. Although the second turbine reached a fairly advanced efficiency level (95 percent), the design still needs to be validated through prototyping. Designing and testing more hydro turbines will enhance the latecomer functional SI capability of Farab. As Figure 6-4 illustrates, the firm has accumulated functional SI capability up to the intermediate innovative level and has started moving towards the advanced innovative level.

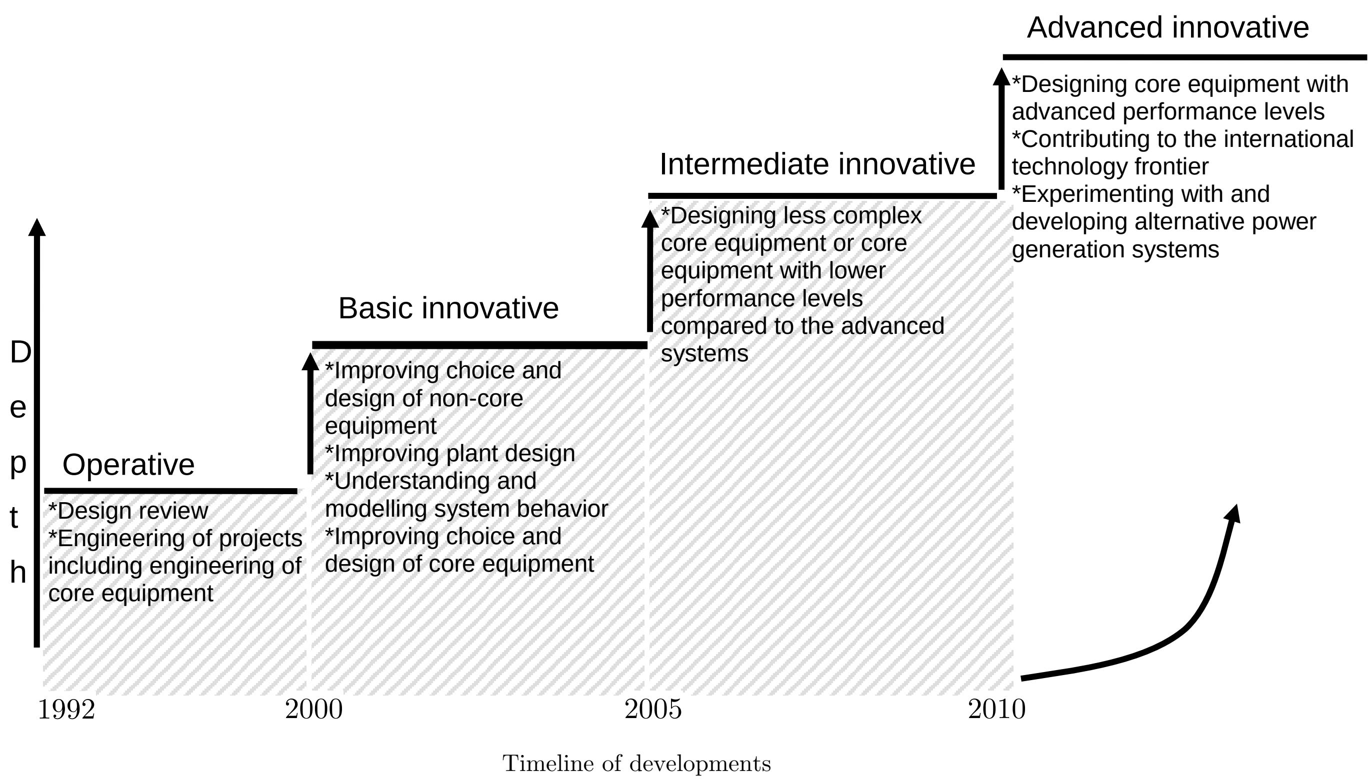

Figure 6-4: the evolution of latecomer functional SI capability in Farab.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

6.4.2 Latecomer project SI capability

When Farab started its initial projects in 1995, there was no local experience in managing hydro power projects. The senior management team hired project managers and the personnel of project teams from candidates with experience in other project-based industries such as the construction of industrial plants and from engineers involved in the operation of hydro power plants. No consultancy or project firm was hired to transfer knowledge of project management.[25] Decisions on how to organise projects, how to categorise project activities for procurement (project execution strategy) and make or buy decisions were made through intensive internal discussions by the embryonic senior management team.

The first and longest discussions took place around engineering and procurement in projects. It was concluded that engineering would significantly affect project management and so should be internalised for exercising effective control over projects. As there was no prior local experience, engineering must be learnt from abroad. The procurement of equipment in projects was perceived to be a lucrative activity requiring specialised engineering knowledge of hydro power plants. The decision was to internalise this procurement as well. More than 10000 parts exist in a typical hydro power plant. One of Farab's first activities was to identify the list of all parts and decide how to categorise them in packages for procurement purposes. The strategy was also to maximise sourcing of equipment from local firms. The initial categorisation and strategy have been continuously revised as the firm has carried out an increasing number of projects. Regarding other tasks, the decision was to outsource installation and erection activities to local contractors but to carry out the project planning and control activities inside the firm.

At that time, the Department of Planning and Project Control was responsible for preparing project plans. The former Head of this department says:

> "Usually there is a basic project plan in the tender documents which needs to be detailed by us. In the first projects nobody helped us in developing project plans. Although the Canadian designer of the projects could have helped us prepare a plan, it preferred not to do so. We prepared a draft in our department and it was

[25] Foreign supervisors, mentioned in the previous sections, were merely involved in organising the Engineering Department and transferring technical knowledge of project engineering.

> finalised through interactions with the client's consultant. This plan caused several problems in the later stages of the projects but we learnt [from these mistakes] and improved upon it for future projects."

Another area of heated discussion was the choice of structure. Farab chose a matrix structure. Various reasons were behind this decision, most notably the need to facilitate the accumulation of engineering knowledge and to attain better economic terms in buying core equipment.[26] In this structure, engineering and procurement activities were carried out by functional units. Every project had a project manager under whom a project team was responsible for following up the related tasks in the functional units, for interacting with the client and sub-contractors, and managing construction activities on the project site. Time and cost control of projects was performed by two separate units within the Planning and Project Control Department.[27]

Although Farab still has a matrix structure, numerous changes have been implemented in the internal structure of the functional departments and also in the division of tasks between them to reduce inter-functional friction and to cope with challenges in the management of the projects (Archives of Farab's organisational charts). For instance, more engineers were employed in the Procurement Department to speed up procurement in projects by reducing unnecessary interactions with the Engineering Department.

In 2002, Farab was about to finish its initial four projects. The stresses of unknowns in project management and the day-to-day pressures of projects had been reduced considerably by that time. Over the course of the next two years, a series of meetings was organised to reflect on the experience of managing those projects, which resulted in the elaboration of 18 major improvement opportunities. For instance, the composition of project teams changed and new authority were delegated to project managers, the project execution strategy was improved to reduce the number of contracts in every project and a new division was created for erection/installation tasks. To smooth the project activities, a Project Control Unit was established in each functional department to organise the functional activities according to the needs of the projects. A new unit was also created in the Planning and Project Control Department for strategic analyses.

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[26] The core equipment of a plant includes the turbine and generator. The rest of the systems are called non-core equipment or auxiliary systems, and provide required services for the reliable performance of core equipment. Examples of non-core equipment include the pressured air system, fire protection systems and air conditioner systems.
[27] In the early days of Farab, the Planning and Project Control Department was involved with coordinating local manufacturing activities and upgrading project management procedures in local firms.

Following the formulation of new strategies in 2004, the Market Development Department was established to actively search for new projects. This department created a unit for gathering market intelligence and monitoring competitors. In parallel, the Engineering Department established a unit to focus on preparing technical bids. As the number of projects increased and the firm diversified into new markets, the organisational structure was revised to include one Deputy Director for each of the four business areas of the firm and a Deputy Director for each of the five functional departments.

Until 2001, Farab had developed its capability in time management and project planning up to a high standard against which some local project firms benchmarked its systems. Around that time, two key professionals of the Planning and Project Control Department left the company over a disagreement with their senior manager. Their analysis of projects had indicated that further improvements in the performance of the projects would require cross-functional changes in the organisation. The Head of Department, however, was opposed to widening the domain of the changes. Project planning and control activities were also devolved to project teams after that incident. As a result, each project employed temporary personnel for planning and controlling the tasks and only regular reports on the costs of projects were centrally prepared for the CEO. The evidence shows that this organisational change reduced the chances of inter-project learning.

By the time that the initial projects were delivered, the cost control capability in Farab had reached a level that the firm could compare the costs of one single activity across projects. This capability permitted Farab to prepare a budget for its projects from 2005. These budgets were effective in stimulating innovation in project management. For instance, under pressure to cut costs, one project team innovated in the quality assurance system by reducing the number of inspection visits to manufacturing plants. This new practice was later adopted by other projects. Similarly, the Engineering Department, under pressure from one project team, changed its workflow to reduce the costs of engineering tasks in that project. This practice was also later extrapolated to other projects by the department.

As has already been discussed, Farab has entered into new markets since 2002. New clients often expect shorter completion times, are more concerned with delays and their strategy is to have a single contractor for dams and hydro plants. Farab's Head of Project Planning says:

> "Hydro projects are long in nature. Our local client often has problems in financing the project and does not expect us to be quick. In the majority of cases,

> we have blamed the civil contractor for delays in our projects because of late preparation of interfaces. Our arguments are acceptable in this context ... but our new clients have already secured the money and are very strict about the time [delays]."

Primarily in response to the expectations of new clients, the firm has embarked upon improving its project management capability. In 2005, Farab benchmarked its project management system against the systems of five local project businesses (including Mapna). In parallel, the firm started to revise its project management procedures based on the PMBOK guidelines and began to fill its gaps by hiring some employees of Mapna as consultants.[28]

The erection and installation division, which was created as a result of discussion meetings in 2002, cut the erection costs by 30 percent in a recently delivered project, and considerable reductions in time have also been achieved. Among the learning practices in this division, engineers are gradually reducing the duration by piloting shorter schedules in one project and copying the successes across all projects.

Two overseas projects have, in particular, significantly affected project management capability in Farab. The client of the Sangtude II project in Tajikistan expected the project to be delivered in 36 months compared to the 60-72 month duration of projects in the local market. The Tana project in Kenya had an even shorter schedule of 25 months. Farab gave special authority to the managers of these two projects in order to realise the shorter schedules.

Generally, major delays in Farab's projects have been caused by erection and installation activities. A Russian contractor was undertaking the Sangtude I hydro plant project in Tajikistan in parallel with Sangtude II.[29] During a visit by a project manager from Farab, the Russian engineers had claimed that they would finish the erection and installation tasks in 12 months, a goal that Farab's engineers considered a joke. The realisation of that promise after a year, however, removed the mental obstacles among Farab's project managers[30] that had impeded them from attempting shorter schedules.

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[28] These improvements are in areas such as risk management, planning, initiation and project closing phases.
[29] Sangtude I hydro plant project is owned by the same Tajik client and is within the same geographical region of Sangtude II.
[30] Previous suggestions to reduce project times were rejected by project teams on the grounds of the impossibility of achieving shorter time schedules.

Intrigued by this encounter, a shorter time schedule was piloted in one project and considerable improvements were achieved.[31] Based on this experience, a faster plan was piloted in the next project, but this project was still ongoing at the time of the fieldwork. The achievements were made possible by changing the division of tasks among sub-contractors, giving more space to the in-house division for erection and revising the sequence of some activities in the project. All these changes could have been tried in previous projects. In parallel, the team of TANA has devised a faster procedure for engineering and procurement tasks. The length of engineering and procurement activities in this project has become a benchmark for other projects.

In addition to the above improvements, Farab is paying more attention to sharing knowledge across projects. For instance, project managers share their experiences through monthly meetings. Meetings with the same function are convened from time to time for other roles in projects, and a procedure for capturing and sharing lessons learned across projects is under implementation. Nevertheless, moving towards shorter time schedules has caused some tensions between project teams and functional departments. A series of discussion meetings were arranged throughout 2008 and 2009 to reveal these problems and find resolutions. As a result of these meetings, a joint improvement initiative has been defined by all departments to reduce the duration of procurement tasks in projects.

Simultaneously with the above developments, the new Head of the Planning and Project Control Department has initiated some changes. The Time Control Unit in the Department has been inactive for some time but has regained its energy under the new management and is actively looking for improvement opportunities in projects. A new system has been designed to mix the currently decentralised approach in project planning and control with a central function. The aim is to increase the use of knowledge generated in separate projects and to ensure that projects are in alignment with Farab's strategies. The plan is to support 25 members of the project teams to get international certificates in project management.

Currently, Farab has projects in other markets and is confident that its project management and engineering capabilities allow for its presence in some other areas.[32] The initial projects of Farab took around a decade to finish, but the record in recent local projects has reduced to five years, and the firm aims to finish its overseas projects in considerably shorter times. At

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[31] For instance, the duration of the erection and installation of the generator was reduced by three months.
[32] The firm has participated in competitions in other sectors such as water purification plants, water transfer projects, the design and construction of transmission lines in an electricity network, and the management of a modern airport.

the time of writing this chapter, Farab had just finished the Tana project in Kenya with a four month delay (taking 29 months in total). Although the delay was primarily caused by the failure of the turbine designer, this record is a considerable leap from the previous durations.[33] In a similar case, a major local manufacturer of butterfly valves has been taken over by Mapna. Under its new ownership, this manufacturing firm moved to other business areas, reducing the reliability of sourcing that type of equipment for future projects. Although there had been discussions in Farab to take over the firm, these discussion did not result in action.

Pre-project

Siahbishe was the first project for which Farab participated in an intensive competition. A team was assembled from the Engineering and Procurement Departments to prepare the proposal under the direct supervision of the CEO. The preparation of the bid took around six months. Farab won the project in competition with Siemens and Cino Hydro China in 2003. According to the firm's new strategies, the Market Development Department was consequently established and that bidding team moved to the new department. Some other experienced individuals from the project teams later joined this department. Currently, there are several regional managers in the department dealing with marketing, finance and bid preparation for each specific region. Although this department was initially expected to prepare the bids independently from the Engineering and Procurement Departments, the load of marketing and financing tasks has resulted in its reliance on the functional departments.

Farab was initially an unknown name in overseas markets. The first challenge of the Marketing Development Department was to promote the brand. One regional manager recalls the first days:

> "Clients in Africa knew Siemens and Alstom but had not ever heard of Farab. We had to inform them that there is a Farab company with experience of managing 7000MWs of hydro plant projects. We had to invite their senior officials to visit our projects and convince them that we can build power plants. But now I sometimes receive calls from African countries that have not even been the target of our marketing activities."

The successful export of systems integration for hydro power generation systems, as with other capital goods, can depend on a variety of factors rather than mere technical merits. For instance, the level of political relations between seller and buyer countries and the history of

[33] Redesigning of the turbine could delay the project for at least six months but managers saved two months by changing the sequence of erection and installation tasks.

trade between the two can affect the 'go' or 'no-go' decision of the exporter. Over time, Farab has accumulated knowledge of some of these critical factors and has built channels in targeted regions to evaluate the opportunities. Another regional manager says:

> "In the first days, we marketed ourselves in several countries in Africa, the Middle East and Latin America. Now we know that the administration system in some countries reduces our chance of success so we do not waste resources in marketing and preparing bids for them. We have created specific policies for every region indicating under which conditions we should participate in their bids ... A committee of senior managers in Farab approves the 'go' or 'no-go' decision for any particular bid."

Effective competition in a particular bid would require, among other things, an understanding of customer needs and knowledge of the aims of competitors in that specific bid. Building this understanding needs an active engagement with clients. Farab has improved its capability for such engagement through preparing more bids and reflecting on its failures. Success in bids also requires a desirable technical proposal and a competitive price suggestion. The growth of engineering and design capabilities in Farab has increased the potential for preparing better proposals. We have illustrated in the previous sections how a better understanding of power plant behaviour and the use of modelling techniques has enabled Farab to offer superior technical proposals. A deeper knowledge of engineering and design can also help propose cheaper prices by enabling engineers to envisage lower-cost alternatives in design. Some related examples are illustrated in the section on latecomer functional SI capability.

Approximately 60 percent of the costs of a large hydro plant are spent on core equipment, putting reliable access to affordable suppliers at the core of price advantages. Farab has developed a database of suppliers by gathering information from exhibitions, journals and official visits over time. In particular, a project was launched in 2007 to scrutinise related manufacturing firms in China to populate a database of possible combinations of price and quality.

The remaining 40 percent of overall costs are spent on project management and non-core equipment, each including some opportunities for improving the performance of bids. For instance, having an in-house erection and installation department has helped Farab formulate cheaper suggestions and has improved the accuracy of price estimations. As the section on functional SI capability shows, the erection costs in Farab have recently reduced by 30 percent and considerably shorter installation times have been achieved in some areas.

Similarly, the creation of a database on the costs of project tasks has enabled the Market Development Department to make better price estimations. In a separate attempt, a database is being created in Farab to contain various aspects of every finished bid, including the prices of competitors, the characteristics of the wining proposal and an analysis of Farab's failure to extract lessons learned. This database is used in preparing new bids.

Non-technical considerations nonetheless can affect the results of overseas bids. For instance, institutes that finance these high-cost projects can also greatly affect the results of the competition. International banks often finance a project on the condition that a certain share of the required equipment or services is bought from the home country of the bank.[34] From another perspective, some firms occasionally offer low prices to win a particular project with very low margins for strategic purposes. As such, the evidence on the success and failure of bids does not accurately reflect the accumulation of pre-project capabilities. The above discussions also indicate that the capability to formulate winning bids depends to a large extent on progress in other areas of LSIC.

Nevertheless, a trend towards improvement can be observed in Farab. The number of cases in which the firm has won or lost a bid with high deviations of estimations[35] has reduced considerably in recent years. Farab's technical proposals have also been ranked as the best or second-best in 90 percent of overseas competitions. In the case of the Tana project in Kenya, Farab won the competition with a difference of only US$ one million in its price proposition from its main competitor. The evidence therefore indicates the existence of a relatively competitive capability for price, time and the technical aspects of the bids. Despite these developments, Farab is currently unable to enter into competitions for fast projects (less than 25 months) as its project capabilities are not geared to such speeds. The firm has also been disqualified in several competitions due to its lack of capability in turbine design.[36]

Post-project

As noted earlier, post-project capability is a key part of the LSIC. Here we see progress more or less in line with other components of Farab's capability development. For example, as a

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[34] As such, systems integrators from countries with strong financial institutions have higher chances of winning international projects.

[35] This occurs when the execution of the project proves that costs were considerably underestimated. Alternatively, it happens when retrospective analysis reveals considerable overestimation of costs as the major reason of the failure of a bid.

[36] People in the Market Development Department generally believe that Farab is in fact marketing for leading suppliers as they gain the biggest share of the value added in projects by engineering and supplying core equipment. This department, therefore, argues for the ownership of design and manufacturing facilities by Farab.

part of its responsibilities, the Engineering Department in Farab produces operation manuals for equipment and educates operators on how to use them. The firm also has professional operators in employment to supervise the personnel of the clients on the project site during the trial-run operation period and the firm has benchmarked a high-performance operational organisation from abroad. Resolving problems during the trial-operation of each plant provides continuing opportunities for improving this operational knowledge in Farab. The evidence therefore indicates the accumulation of attributes for post-project capability within the firm.

The motivation of Farab to enter into the operation of plants is not merely financial, as this business has very low margins in Iran. Incidents during the operation life of plants built by Farab, however, have led to long disputes with the local client. Although thorough investigations in all cases so far have revealed careless operation to be the main cause, disputes have taken a great deal of time from the senior management team and have damaged the image of Farab. The firm is therefore highly motivated to take over the operation of its plants to prevent such incidents.[37]

The evidence shows that Farab has been formulating operation proposals for the local client since 2000. The firm has even suggested visiting the plants and evaluating the status of existing operations free of charge. These suggestions, however, have been refused by the client primarily based on the legal limitations that force it to sign short-term operation contracts.

Despite these challenges, the firm deploys other mechanisms to get feedback from the post-project phase. Every hydro power project has a trial-operation period during which Farab operates the plant and trains the employees of the client. Farab's engineers analyse the operational problems in this period and provide feedback to the Engineering Department on those problems that have originated from weaknesses in project engineering. In addition, Section 2.1 shows how intensive engagement of the Engineering Department with the analysis of failures in equipment leads to building stronger functional SI capability. Farab's policy is to engage with such incidents to enhance its capabilities, although the firm may not be legally responsible in these cases. Engineers often have interactions with operators during this activity and get feedback on a variety of design issues. For instance, it has been suggested by

[37] The maintenance of hydro power plants requires knowledge of dismantling complex equipment and troubleshooting their components. Every component has a troubleshooting procedure that is supplied by its manufacturer and the dismantling process is apparently the reverse of the erection/installation process. The erection/installation division of Farab has already carried out these activities through erection and the trial run of power plants.

operators that engineers use a different material for some components of the hydro turbine or change the layout of the piping system to ease operation and maintenance activities.

Analysis and interpretation

Elements of project management capability such as knowledge and palnning skills for project planning, drafting project strategies and organising projects were initially built independently by the firm and were improved over time as the firm learnt by managing more projects. The knowledge of the time and costs of project tasks has improved, enabling the firm to increase its control over projects. When the first four projects were about to finish, opportunities were created in the organisation to systematically reflect on its experience. A number of improvements were implemented at both the firm and the project levels as a result of these reflections. A particular example was to vertically integrate across the value chain for taking over erection and installation activities from sub-contractors.

Before diversifying into new markets, Farab's project capabilities were developed in harmony with local demand which had lax expectations of the duration of projects. Quicker durations demanded by new clients forced the firm to move away from local standards of project management towards international ones. Mental barriers of project managers to realise shorter durations were overcome by monitoring a fast project undertaken by a foreign competitor. Risk-taking and creative managers were given the authority to try new strategies with the hope of diffusing successful strategies to other projects. In parallel, the firm started learning from project firms in other local markets, and revising its project management procedures to incorporate the international guidelines of project management, such as PMBOK. In addition to allowing for a faster completion of existing projects, accumulation of stronger project capabilities can, in particular, expand possibilities in overseas markets.

Figures 6-5 to 6-7 illustrate the status of latecomer project SI capability in terms of its pre-project, project and post-project parts. Aggregating the three parts into one figure would result in the loss of some significant details and decrease the accuracy of the analysis. As Figure 6-5 shows, Farab has accumulated some elements of intermediate level of project capability, but has not yet matured it. The firm still cannot exercise control over the industry value chain to secure the supply of core equipment and its overall strategies are not cascaded effectively to projects. However, the evolution to its current position has not been in a deterministically upward direction. The project capability has remained quite stable over a considerably long period, compared to a relatively continuous upgrading in functional SI capability, as internal ambitions to progress waned when some key individuals left the firm, and because the local client was satisfied with the status quo of speed in projects due to its inability to finance faster projects.

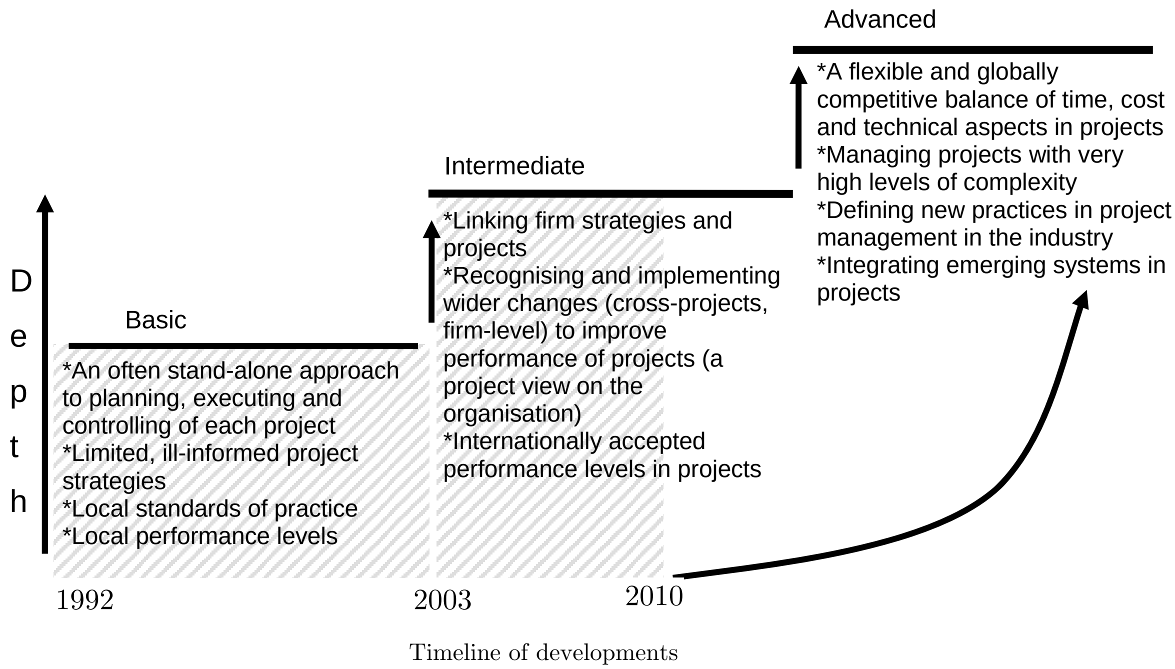

Figure 6-5: the evolution of latecomer project SI capability in Farab: project part.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

Figure 6-6 shows that the firm has accumulated the pre-project capability up to the intermediate level. The market possibilities of the firm are limited mainly due to the lack of strong turbine design capability and the distance from the international norms of project completion time. Figure 6-7 illustrates that Farab has accumulated some attributes for the intermediate level in post-project capabilities, although no formal operation contract has been signed.

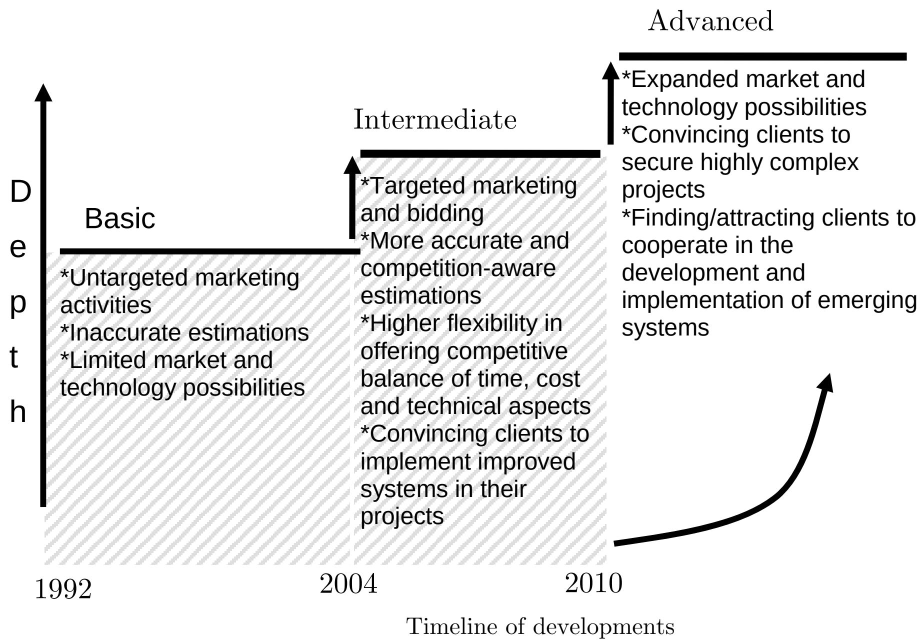

Figure 6-6: the evolution of latecomer project SI capability in Farab: pre-project part.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

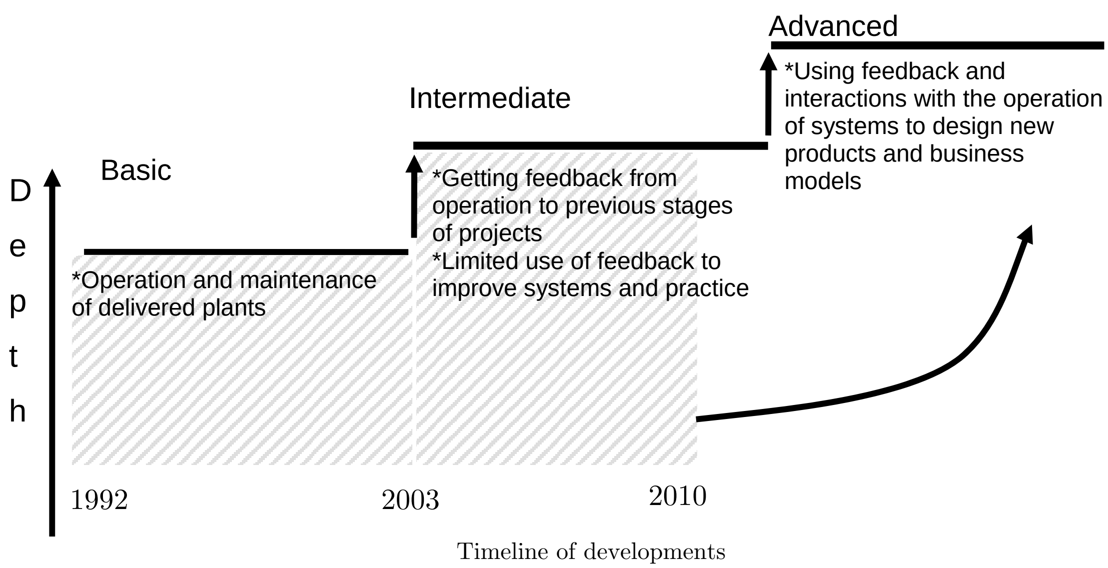

Figure 6-7: the evolution of latecomer project SI capability in Farab: post-project part.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

6.4.3 Strategic SI capabilities

Farab was established by Iran's Ministry of Energy as a project management company. The aim was to cut the costs of hydro power plant projects by replacing expensive international firms and to increase the share of local content in projects. Leaders in the local industries were pessimistic about the successful establishment and continuing operation of Farab due to the lack of local experience in complex projects.

The building of strategic capabilities was a daunting challenge to Farab. At the outset, there was no similar systems integrator in Iran to learn from or emulate and it seemed incomprehensible to the senior management team to design their organisation based on leading international firms. Decisions made by the initial senior management team in Farab impacted the direction of LSIC evolution in the firm. This section focuses on the background of four members of the board.[38] Three of them, namely Mr. Hajirasoliha, Mr. Marjuvi and Mr. Safaee Farahani were (previous or present) officials of Iran's Ministry of Energy.

Mr. Safaee Farahani was CEO of Tavanir[39] and had played a key role in promoting the idea of local project management companies in the Ministry of Energy after the Islamic Revolution. Mr. Hajirasoliha was previously the Head of the Office of the Minister for managing state-owned manufacturers in the local electricity sector. Mr. Marjuvi was, however, the Head of the Office of the Minister for expanding manufacturers in the local electricity sector. In effect, these two individuals were among the key figures in developing local capabilities after the Islamic Revolution. Mr. Marjuvi was chosen as the Chair of Board and Mr. Hajirasoliha an acting member of the Board. Mr. Hajirasoliha played a significant role in early discussions and led the efforts to organise the internal activities in the firm. The first CEO of Farab was Mr. Mahnama, who had had a long career in Sadid Industrial Group. Sadid specialised in manufacturing heavy equipment for industrial projects in Iran. Mr. Mahnama was a firm believer in expanding local manufacturing firms. After him,[40] Mr. Hajirasoliha was chosen as the CEO in 1996 and remained in this position until he retired in 2009.[41]

Deliberating on strategic issues and improvement opportunities form a key part of the management culture in Farab. The regular issue-centered discussion meetings of the senior management team[42] have been notable elements of this culture since the establishment of

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[38] Mr. Erfanian was another member of the board. He was previously the project manager for the development of Foulad Mobarake steel company. He left Farab after a few months.
[39] Tavanir is the Power Generation, Transmission and Distribution Management Company of Iran.
[40] Mr. Mahnama left Farab in 1996 and became a leading figure in the Industrial Development Organisation of Iran where he diffused the organisational structure of Farab in other energy projects, creating some competitors for the firm.
[41] The current CEO of Farab is Mr. Lotfi, who was promoted from being the Deputy Director for large hydro projects.
[42] In terms of structure, every large hydro project had a Deputy Director in the early days. As such, Farab initially had four Deputy Directors for its projects and four Deputy Directors for its functional departments. As the number of projects increased and the firm adopted new strategies, the structure was revised to include one Deputy Director for each of the four businesses of

Farab. Strategic decisions such as organisational structure, project strategies and technology strategies have been made through intensive discussions in early meetings. A major strategy, in terms of its impact on capability evolution, has been to create a local chain of component suppliers. A board member of Farab describes the atmosphere in those meetings:

> "He [the first CEO] had a remarkable self-confidence and believed that every type of equipment of a hydro power plant can and should be manufactured in Iran. He believed that it did not matter if this approach created a couple of months of delays in projects. He believed that we should use this opportunity to develop the local industry."

Creating the local supply chain captured a share of Farab's resources. Due to the lack of prior experience in local firms, Farab initiated a long process of identifying potential local suppliers and matching them with international firms for upgrading. The aim was to negotiate a scope of divided supply between international suppliers and local companies[43] so that an acceptable level of quality was achieved in the local firms under the supervision of international firms. Farab accepted the risks of possible deviations in projects and provided financial help to the local suppliers to acquire capabilities. Although local products and services were cheaper, the supply was sometimes unreliable and caused delays in projects. After all, it was difficult for managers who had spent years in developing local content to allow imports in their new positions. Mr. Hajirasoliha recalls an incident:

> "After five years, our CEO was still very persistent in local sourcing, very, very persistent ... this approach occasionally created problems for our projects ... a debate started in the board about how a trade-off should be made between sticking to the local content, meeting the time schedule in projects, controlling the costs and delivering to the desirable quality. Our CEO believed that the local content had the highest importance but others thought the priorities are in the following order of importance: quality, time, price and then local content. We documented this order and it was formally approved by the board although the CEO did not agree. This order of priorities has been a key part of our organisational values since then."

After commissioning the first plants in 2002, the meetings focused on extracting the lessons learned from the past and improving the business. Some results of these meetings have already been presented in terms of taking over installation/erection tasks in projects and making changes to the structure. During these sessions, the future of the company also

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the firm and five Deputy Directors for the functional departments. Deputy Directors and key managers beneath them are regular participants in senior management team meetings.

[43] For simplicity of discussion, we will focus on hydro turbines as an example, but the same procedure was followed for other equipment. When an international supplier of turbines was chosen for a project, it was invited to assess the manufacturing capabilities of local suppliers. Based on this assessment, following negotiations determined which parts could be manufactured in Iran and what changes/upgrades should be made in the local supplier.

emerged as a challenge. The outlook of the demand in the local market was not promising and a number of local competitors had arisen. The CEO of Farab describes the situation:

> "Farab was happy starting with four projects in 1992 but was concerned not to win sufficient business until around 2002 with only three new projects that we had won in this period. But our worries were reduced somewhat because at least we had learned about all the stages of hydro projects, our speed had improved and our designs had become better ... our [leading] foreign partners believed that managing four simultaneous large projects in 1992 was an impressive job for a beginner with no experience ... it was a very big achievement ... [in 2002] we knew our capabilities and we knew our levels of efficiency. Our estimates [in 2002] indicated that we had extra [free] resources in the organisation... Although we had three new projects we had to look into the future very soon."

Revising the scope of business in the face of opportunities/threats became the subject of a series of discussion meetings. Reducing the size of the business was one option in the face of diminishing demand in the local market. However, the idea was rejected considering the potential of the overall positive environment in the firm and the inclination towards growth after its early successes. Instead, various diversification opportunities were explored within the limits set out by Iran's Ministry of Energy as a major stakeholder. The final decision was to keep systems integration of hydro power generation systems as the main identity of the firm and to expand into overseas markets for hydro plants. Since the firm lacked experience in overseas markets, Farab decided to explore the local market for other energy projects to reduce the risks. Its name was therefore changed from 'Farab: Contractor of Hydro Power Plants' to 'Farab: Energy and Water Projects'.

A formal strategic planning initiative was launched in 2004 to examine the implications of these diversifications and to prepare a change plan by engaging with employees at different levels of the firm. In the end, an intriguing vision was formulated: "we will transform Farab into the largest contractor of energy projects in Iran and will gain a decent share in overseas markets". Following the new strategies, the Market Development Department was created to actively look for new projects and other new departments were also established for managing thermal power plant projects and oil and gas projects. In 2007, this strategy was revised and a tool was used to operationalise the strategies at the departmental level. At the time of fieldwork, the strategy plan was under another revision.

In 2004, the firm was assessed against the EFQM excellence model and was ranked the third among over 50 Iranian firms that had participated in the exercise. In preparation for this assessment, a number of committees[44] were organised across the organisation for discussing and implementing improvement opportunities. For instance, around 60 middle managers from across the organisation now participate in excellence committees to discuss strategic issues at various levels. The highest excellence committee is chaired by the CEO, as part of the same discussion meetings among the senior management team that were noted previously. This committee convenes fortnightly to explore overarching issues and decide on areas that span functional borders.

The firm has also developed other mechanisms, throughout the organisation, for sensing changes in technologies and markets and for identifying internal improvement opportunities. A number of these mechanisms have been illustrated in previous sections on project and functional SI capabilities. For instance, the Market Development Department has developed relationships and channels for monitoring markets and gathering information on competitors.

The recent pressure to reduce project durations has renewed ongoing discussions about delays in engineering and procurement activities within the organisation. As some managers remember, these challenges have been identified for a long time and efforts to resolve them have failed so far. The Head of the Planning and Project Control Department says:

> "We [Farab] are not bad at identifying improvement opportunities but implementing the changes is sometimes very difficult ... some of these opportunities were known for a long time and the failures in implementing them had created pessimistic views about possibility of specific changes in the organisation... [before 2009] when we started to engage with a change that spanned functional borders, some people expressed their despair right from the start ... but in 2009 our unit started to play a more active role in coordinating these changes. We were successful in one important case. The deputy director for hydro projects asked me recently to define and coordinate another change program to improve interactions between projects and engineering department. I think our unit is finding its role to be a neutral coordinator of these changes... However, we still have some strategic problems. For example, firm-level strategies are not cascaded satisfactorily, as I hoped, to projects. We asked a project team in our thermal business to give us a copy of their project time plan. We wanted to mix the decentralised approach in project planning with some levels of central planning. They replied that they have not yet prepared the plan. But in reality, it meant they thought we were not in a position to enter into their territory and they knew better how to organise their projects... I discuss these issues with our CEO."

Identifying and responding to challenges and opportunities, however, has been unsuccessful in some cases. The firm cannot exercise effective control over the value chain of the industry to

[44] Such as excellence committees, organizational systems committee, human resources committee and training committee.

secure the supply of equipment or to maximise its gains. Farab did not take the opportunity to buy a local manufacturer of a core component and the focus of the firm changed after being taken over by Mapna, creating challenges in low-cost sourcing of that component. From an internal perspective, although functional SI capabilities have grown over time, the organisation of engineering and procurement tasks for projects has remained largely unchanged, causing delays in some projects. The recent managerial change in the Planning and Project Control Department has, however, reinforced the implementation of cross-functional improvements and promises a more systematic treatment of strategic issues.

Analysis and interpretation

As Figure 6-8 illustrates, the firm has moved towards building the intermediate level of strategic SI capabilities but has not yet matured it. Passing the laborious days of organising and learning the basics of the business, Farab has more time to sense and discuss changes and respond appropriately. Forces of competition in new markets have also increased the commitment to improvements. Although certain bottom-up channels exist for sensing and discussing strategic issues, top-down initiatives to translate the firm-level strategies into operation and to implement cross-functional improvements are weak.

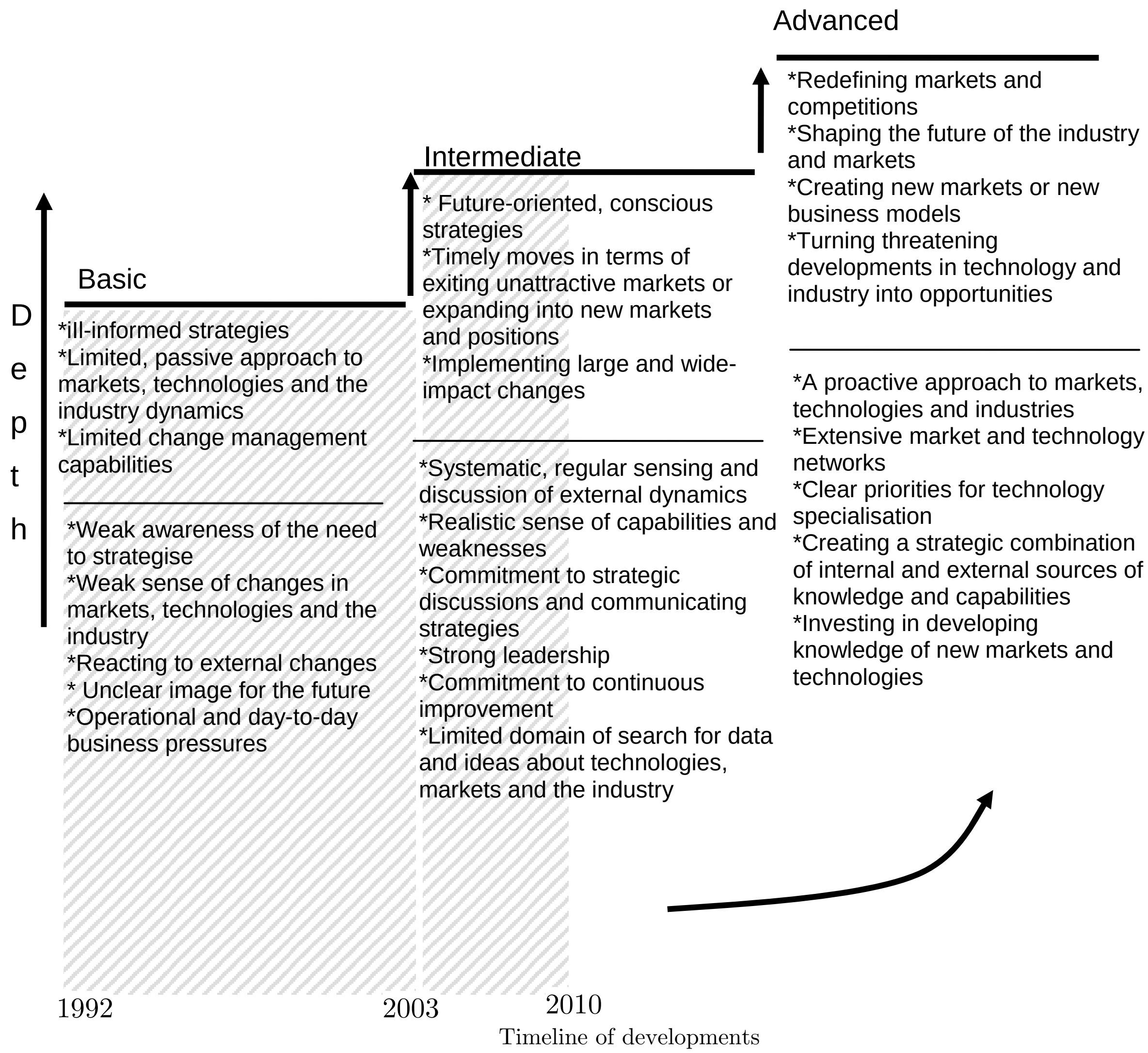

Figure 6-8: the evolution of latecomer strategic SI capability in Farab.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

6.5 Summary

This chapter presents the evidence on the development of micro-level attributes such as people, knowledge, processes and structures that underlie each capability along the changes in products and outcomes of activities to investigate the evolution of the three core constituent parts of LSIC. This approach reveals a picture of the evolution embedded in the wider context of the dynamics in the firm and its external environment.

Farab was created as a project management company in the hydro power industry of Iran but gradually progressed in building wider and stronger capability attributes so that currently it is building the advanced or intermediate level across all three core constituent parts of LSIC according to our framework. This journey, however, has been complicated and the firm still has a complex road ahead to mature its advanced capabilities.

At the outset, the lack of local experience in this industry coupled with the preference of the senior management team in developing local content caused some difficulties in the capability building process from two major viewpoints. Firstly, identifying and upgrading local suppliers captured organisational resources that otherwise could have been focused on the development of LSIC in the firm. Secondly, initial strategic decisions such as make-buy decisions in the case of turbines and installation/erection were based on a partial understanding of the industry value chain. These decisions slowed down the acquisition of advanced technological/organisational capabilities and led to some limitations in market possibilities in the future. The intensity of competition in overseas markets and political challenges surrounding Iran' s economy are likely to cause challenges in securing new projects and in accumulating advanced LSIC.

The evidence indicates the importance of learning from failures in technological and market aspects to the enhancement of LSIC. Analysing technological failures, through an independent step-by-step trial and error effort, led to the accumulation of sophisticated modelling and simulation attributes, enhanced understanding of system behaviour, identification of design-related capabilities in the wider innovation system of the country in the later stages, and increased the self-confidence within the firm. It also led to the discovery of the turbine design process within the firm. Similarly, reflecting on failures in bids has demonstrated the strategic necessity of building turbine design capabilities for success in overseas markets. In retrospect, engineers analogise those cases of failure analysis to a university, reflecting the plethora of learning opportunities that they created.

Learning through projects appears significant in the evolution of LSIC. Functional and project SI capabilities were enhanced by experiencing and solving a new set of challenges in each project. Working with various turbine technologies and contemplating the unique design styles of some leading firms strengthened functional SI capabilities. Nevertheless, this learning did not occur automatically. It required a 'will' to improve, proper organisational arrangements for getting feedback from the later stages of projects, arrangements for sharing knowledge between projects and ambitious employees, and was facilitated by finding external benchmarks.

Evidence shows that the three constituent parts of LSIC fed into each other and co-evolved during the journey. For instance, formulating better bids/offers depends in part on functional and project SI capabilities for understanding the client's needs and formulating proper estimations. Similarly, progress in these two constituent parts depends on the former, the pre-project capability, to secure more projects, the lifeblood of a project business. From another perspective, intermediate strategic SI capabilities created an overall condition in the firm conducive to continuous upgrading in the other two parts.

This case study reveals that attributes underlying capability for one activity can be built through other activities. Some important attributes for turbine design were acquired during the analysis of failures in the delivered systems. Likewise, attributes accumulated through the repetition of design review and project management in several projects were used in assessing the conceptual design of new plants.

External forces coupled with internal aspirations were significant in the evolution of LSIC. The evidence shows that the firm did not initially aspire to compete in overseas markets. However, the emergence of uncertainties in securing new projects in the local market after finishing the first four projects necessitated exploring new markets in response to the internal desires for growth. Exposure to intense competition in overseas markets, within the region and in African countries, affected the evolution of project SI capabilities by challenging the status quo in project time and cost standards. It also stimulated the development of stronger functional SI capabilities to formulate better bids and expand market possibilities.

Clients, as another instance of external forces, impacted the evolution of LSIC. The local client played a significant role in initiating the growth of LSIC. Farab had no project reference at the beginning and was formally unable to participate in bids. Despite this initial support in terms of ignoring the lack of project references by the local client, the lack of orders from the client for designing turbines locally impeded the accumulation of the intermediate level of functional SI capabilities for a period of time. Eventually, the firm had to invest in a small hydro plant itself to exercise and develop its design capabilities. In contrast, the shorter time schedules demanded by overseas clients pushed the firm towards accumulating higher levels of project SI capabilities.

The evidence reveals that the existence of a will to improve was necessary for the development of capabilities. This 'will' was motivated by a range of internal and external factors such as pressures from the client, acts of the competitors and challenges set by the management. There were even occasions in which the required ingredients for building higher levels of capability existed but the transformation was not attempted due to the lack of such 'will'. For instance, shorter project schedules were realised in response to pressure from foreign clients and the breaking of internal mental barriers through monitoring a competitor. Similarly, a new concept for a turbine control system and major technological optimisations in plant designs were envisaged under the firm's objective to control project budgets. A closely related factor in the development of LSIC was self-confidence and self-motivation among the employees of Farab. Self-motivated engineers initiated the process of analysing failures in the turbine and continued to enthusiastically explore the process of turbine design, leading to the development of some important attributes of latecomer functional SI capability. Similarly, the overall motivation of employees towards the growth of Farab was critical in the strategic decision to move into overseas markets and diversify into other local project markets.

Evidence shows that leadership was significant in the evolution of capabilities. The experience and views of the senior management team led to systematic attention being given to building engineering capabilities from the outset. Changes in the import-substitution attitudes of the senior management team after some years shifted the focus from upgrading local suppliers towards more attention being given to developing LSIC within the firm. Similarly, a change in the Head of the Planning and Project Control Department revived the efforts to cascade firm-level strategies to projects and to undertake cross-functional improvements.

The case study also shows that structure and deliberate changes in the organisation impact the development of LSIC. In Farab, devolving project planning and control activities to project teams slowed down the enhancement of some project capabilities. Similarly, a new form of organisation for gathering technical feedback at the project sites provided systematic inputs to improving the functional SI capabilities.

Finally, an aspect of the evolution towards higher levels of LSIC was the existence of organisational resources to look beyond the chaos of daily project challenges to envisage wider-impact initiatives. During the first four projects, Farab was so extensively engaged with organising the projects that few such opportunities were explored. Likewise, the increasing workload of the Engineering Department impeded improvements in the organisation of activities despite achievements in their technical aspects.

Despite the difficult challenges it has faced, Farab has made strong progress in catching up against the three core constituent parts of LSIC. In less than 20 years, LSIC has evolved from small beginnings in project management to having a significant position, underpinning success in both local and overseas markets (regional and African) for large-scale hydro power plant projects.

The next chapter investigates Mapna as the second case study in this research to provide evidence on the evolution of LSIC in a slightly different technological context. Combined with the current chapter, these two empirical chapters provide a basis for cross-case analysis.

7. Chapter Seven: Mapna, a case of strong project SI capabilities

This chapter investigates the evolution of latecomer systems integration capabilities in Iran's Power Plant Projects Management Company (Mapna)[1] as one of the two core case studies of this research. Mapna was established by Iran's Ministry of Energy in 1993 to manage thermal power plant projects in Iran. The firm grew rapidly over time, from sales of US$ 0.39 billion in 2002 to US$ 3.10 billion in 2009, and diversified into the ownership of power plants, providing maintenance and operation services to power plants, and entered into local markets for other energy projects and rail transport projects. As of March 2010, about 41 percent of the thermal electricity generation capacity in Iran was built and delivered by Mapna (Tavanir, 2009). This chapter investigates the evidence to address the main research questions of the thesis on the nature and evolution of LSIC. In particular, it investigates the composition of LSIC, the level or depth of its core constituent parts, how LSIC has evolved over time and the motivations or driving forces behind its evolution.

The evidence in this chapter is based on the data gathered through in-depth interviews with (a) current and former key individuals in Mapna; (b) informants in local client organisations; and (c) consultants who have worked with Mapna. Data has also been gathered from the annual reports of Siemens and Ansaldo Energia from their periods of cooperation with Mapna, as well as relevant documents from Mapna translated from Persian. The presented evidence reveals how Mapna initially offered low-cost project management services but gradually accumulated wider and deeper systems integration capabilities. This led to the acquisition and development of sophisticated capabilities in engineering core equipment of power plants and understanding the behaviours of these complex systems. The evidence also indicates how this course of development was affected by external factors and internal aspirations. Based on our conceptual framework, we show that the firm has accumulated the intermediate level of latecomer project SI capability, and is currently building the intermediate levels of functional SI capabilities and strategic SI capabilities.

The chapter is organised into three sections. It starts with an introduction which presents a brief chronological account of the developments in the firm as a point of reference for the following sections. The chapter continues with an in-depth section presenting detailed

[1] http://www.mapna.com

evidence of the evolution of each constituent part of LSIC. The final section summarises this chapter and discusses several findings.

7.1 Context of establishment

Mapna was established in 1993 for the management of thermal power plant projects in Iran.[2] The economic analyses performed by the Ministry of Energy had shown that 75-80 percent of the costs in power plant projects were spent on buying equipment, and the rest was spent on engineering, project management and installation, which was still a significant sum. The main objectives in establishing Mapna were to provide a cheaper solution for public investment in power generation, to support the growth of feasible local content and to facilitate technology transfer to local manufacturers (Refan 2003). However, the firm has developed its activities into areas beyond its initial mission.

7.2 Developments up to 1998, growing as a prime contractor

The background leading to the establishment of Mapna was similar to that of Farab with the exception that, before this time, the Ministry of Energy had delivered the Shahid Rajaee power plant project under an arrangement different from a turn-key scheme. A project office in Tavanir acted similarly to a prime contractor for this project by coordinating several contractors involved in the project. The difficulties that were experienced under this arrangement led to a revival of turn-key schemes but Mapna was established to replace expensive international prime contractors. The Ministry of Energy awarded the Arak (Shazand) project to Mapna in 1994 to initiate the growth of the firm.

During this stage, Mapna focused on learning how to organise for the management of power plant projects. The first CEO of Mapna, Mr.Marjuvi was previously an influential figure in promoting local content in the Ministry of Energy, and believed that time should not be wasted on trial and error learning in prime contracting. Mapna therefore hired Monenco Agra Canada Co. to organise the firm and transfer knowledge of project management.

The strategy of the firm was to focus on project management and to buy in other services and equipment from contractors. In particular, core equipment of power plants and the related engineering services were fully bought from international firms. For other sections (non-core

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[2] Mapna was established as a private company with funds from Iran's Ministry of Energy and Iran's Industrial Development Organisation. In 2004, it changed to a public joint company and its shares were sold on the Tehran Stock Exchange.

equipment block[3]), in line with the Ministry of Energy's policies, Mapna joined international firms with capable local firms to cooperate in the engineering, manufacturing and construction of equipment with the hope of replacing foreign firms in the future. Where possible, Mapna facilitated technology transfer to local firms.

As Table 7-1 shows, the Ministry of Energy awarded six other projects to Mapna during this period, including a total of 14 steam power units. These projects were granted on a price offer basis and were aggregated into a package called 6 CC (Combined Cycle) to create appropriate conditions for technology transfer to the local firms. The number of employees in Mapna increased from 16 at the time of its establishment to 348 in 1998, out of which 276 (equal to 80 percent) had higher education degrees (Mapna Catalogue, 2009).

Contract signed in	Project Name	Capacity (MWs)	Turbine	Supplier	Location
1994	Arak (Shazand)	4*325=1300	Steam	DEC-China	Iran
6 CC package-1996	Montazer Ghaem	3*107=321	Steam in CC	Siemens	Iran
	Rajaee	3*100.6=301.8	Steam in CC	Siemens	Iran
	Khoy	102.7	Steam in CC	Siemens	Iran
	Fars	3*98.3=295	Steam in CC	Siemens	Iran
	Nishabour	3*100.5=301.5	Steam in CC	Siemens	Iran
	Shariati	107	Steam of CC	Siemens	Iran

Table 7-1: List of projects awarded between 1993 and 1998.

7.3 From 1998 to 2002, vertical integrations

In 1998, Mapna was awarded a package of projects called 30 Gas Units (later amended to 40 units). This package of six power plant projects was designed to allow, in particular, technology transfer in the manufacturing of gas turbines and generators. Furthermore, following the trend of the previous stage, most international contractors of non-core equipment were gradually replaced with local firms during this period.

[3] The core equipment block is the section of a power plant that generates electricity. As for its equipment, different categorisations can be used in practice. In this research, the core equipment block includes core equipment of a plant: the turbine, generator, boiler and their auxiliary systems for optimized performance. Other sections in a power plant, such as cooling towers and water treatment systems, are considered as non-core equipment block. When the term 'engineering of core equipment block' is used in this chapter, the emphasis is on the layout of core equipment block and how the core equipment interface with each other rather than engineering of a single system. The latter task is known as engineering the core equipment.

To secure access to project resources for the rapidly growing local market, Mapna vertically integrated into the engineering of power plants, the manufacturing of core equipment and the construction business at this stage. It acquired the majority of shares in Monenco Iran, which was an engineering company with a focus on projects in the electricity sector. Ansaldo Energia, from Italy, won the international contest for supplying turbines and generators in the 30 Gas Units package on the condition of transferring manufacturing knowledge to Iran. Mapna established TUGA (Mapna Turbine Engineering and Manufacturing Co.) to become the transferee in this arrangement. TUGA constructed a modern factory and acquired the manufacturing knowledge through a five-year technology transfer agreement in which TUGA[4] acted as a manufacturing sub-contractor for Ansaldo and gradually took up wider roles in manufacturing. Mapna acquired the majority of shares in another local company, Pars Generator, which became the transferee in a similar technology transfer agreement with Ansaldo. Pars Generator therefore evolved to be a manufacturer of generators for gas-fired plants. Mapna also acquired Nasbniroo, which was a construction company with a background in the installation of core equipment in local thermal power plant projects.

Another important development at this stage, from a capability evolution perspective, was Mapna's participation in the competition for the Mobin project, which was its first attempt to win a project outside the local electricity market. As will be discussed later, this project led to the development of certain engineering and project capabilities in Mapna. Similarly, the firm won its first international project in Reysut, Oman.

By the end of this stage, Mapna had evolved from a mere prime contractor for thermal power plants to an integrated company with bases in manufacturing core equipment, engineering non-core equipment and the erection of projects. The firm was, however, still reliant on international leading systems integrators for engineering core equipment according to the requirements of each project.

Contract signed	Project name	Capacity (MWs)	Turbine	Supplier	Location
30 Gas Unit package	Kerman	8*159=1272	Gas-V94.2	Ansaldo[5]	Iran
	Kazeroun	4*159=636	Gas-V94.2	Ansaldo	Iran
	Damavand	12*159=1908	Gas-V94.2	Ansaldo	Iran
	Sanandaj	4*159=636	Gas-V94.2	Ansaldo	Iran
	Shirvan	6*159=954	Gas-V94.2	Ansaldo	Iran

[4] TUGA established a new company, PARTO, for manufacturing turbine blades. The technology of blades was not included in Ansaldo's contract. PARTO went through reverse engineering and negotiated separate transfer agreements with specialised suppliers to manufacture the blades. It eventually got a license from Doncaster in 2007.
[5] Ansaldo was a Siemens licensee.

	Hormozgan	6*165.1=990	Gas-V94.2	Ansaldo	Iran
	Sahand	2*325=1300	Steam	SEC-China	Iran
	Abadan	4*123.4=493.6	Gas	GE F9	Iran
	Mobin	6*123.4=740.4	Gas	GE F9	Iran
	Raysut	30	Gas	GE	OMAN

Table 7-2: List of projects in this period.

7.4 From 2003 onwards, competition and diversification

At the beginning of this period, Mapna was awarded a package of power plant projects called 22 CC on a price offer basis, and won another package called 3000 MW in a contest in the local market. These two packages of projects were significant in the course of capability developments within the firm.

The projects in 22 CC were aggregated by the state client to provide incentives for technology transfer of core equipment in combined cycle plants. Building on this market, Mapna negotiated a number of license contracts for manufacturing core equipment of power plants in Iran. As a result, TUGA and Pars Generator gradually migrated to new licenses from Siemens. A separate contract was signed with Siemens for transferring the knowledge of engineering combined cycle power plants to Mapna. This contract included the transferal of a set of documents and a training programme in which a variety of courses were conducted in areas such as engineering, project management, general management and bid preparation. Around the same time, Mapna Boiler Co. was established to design and manufacture boilers in combined cycle plants under a license from Doosan. In addition to these impacts, the need for certain technical customisations in combined cycle plants incentivised further development of systems integration capabilities in Mapna. The details will be discussed in the following sections.

The 3000 MW package was also important from a functional SI capability perspective. The senior management of Mapna expected local engineers to learn the engineering of the core equipment block as part of this package. As such, an arrangement was finalised with Ansaldo in which Mapna gradually learnt basic engineering of the core equipment block and engineering of core equipment according to the client's requirements. The strategy of Mapna later changed and the firm migrated towards the engineering style of Siemens, discarding Ansaldo's approach.

The Ministry of Energy started promoting private investment in the power generation sector in 2003 in order to respond to the rapidly growing local consumption of electricity. Mapna took this opportunity and invested fully or partly in the South Isfahan, Tous and Assaluyeh plants. The firm developed its own style of engineering the core equipment block in these three projects by learning some elements from Siemens, working with smaller specialised suppliers in Europe and trial-and-error learning. Further discussions about this development will be provided in the following sections.

Nevertheless, there was no guarantee that other private investors would buy equipment and services from Mapna. In fact, the evidence shows that in the first three years after 2003 some private investors preferred to buy new versions of core equipment directly from Siemens.[6] At the same time, the local state client started promoting competition from other local contractors. Facing these competitive threats, Mapna crafted new strategies.

One strategy was to diversify into the local market for other complex products and services. A new market was rail transport in which Mapna secured a contract from the local client for manufacturing 150 passenger locomotives under a Siemens license. Mapna also decided to enter into the operation and maintenance of thermal power plants and to explore the local market for oil, gas and petrochemical projects. To prepare for these new growth strategies, the firm went through a restructuring programme in 2006 and was transformed into a holding with six divisions.[7]

As another part of the strategy, R&D departments were recently created across the holding and several technological projects were set up to understand the behaviour of systems in power plants and to modify the equipment currently manufactured by Mapna. A head of project engineering in Monenco speaks about the reasons why modifications had not been attempted previously:

> "Our conditions did not incentivise it. Our production volume of core systems was very close to the market demand so it was acceptable for our manufacturing firms to invest less in optimisations and modifications of the equipment. Furthermore, because of the context, we did not have strong competitors for supplying the equipment so enough resources were never given to people in the manufacturing firms for modification purposes."

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[6] Fortunately for Mapna, the new round of embargos resulted in the freezing or cancellation of several contracts with Siemens, and Mapna regained a dominant position in the local market.
[7] In this structure, one division, the EPC division, is responsible for managing power plants. Under this division, three EPC companies have been established: Mapna Development 1 (for gas powered plants), Mapna Development 2 (for combined cycle plants) and Mapna Development 3 (for customised plants). This division also manages Monenco (engineering) and Nasbniroo (construction) companies. The aim was to bring all resources for managing power plant projects under one umbrella. Another division, EMAN, manages the engineering and manufacturing of core equipment for power plants. All the manufacturing facilities of Mapna are organised under this division. A new division was also created, O&M, to deliver operation and maintenance services for power plants, and to provide feedback from the operation of the plants to the EMAN and EPC divisions.

Contract signed	Project name	Capacity (MWs)	Turbine	Licensor	Location
22 CC package	Neka	160	Steam[8]	Siemens	Iran
	Yazd	160	Steam	Siemens	Iran
	Kazeroun	3*160=480	Steam	Siemens	Iran
	Kerman	4*160=640	Steam	Siemens	Iran
	Damavand	6*160=960	Steam	Siemens	Iran
	Sanandaj	2*160=320	Steam	Siemens	Iran
	Shirvan	2*160=320	Steam	Siemens	Iran
	Jahrom	2*160=320	Steam	Siemens	Iran
	Yazd-solar	160	Steam	Siemens	Iran
3000 MW package	Parand	6*159=954	Gas-V94.2	Ansaldo	Iran
	Urumiyeh	4*159=636	Gas-V94.2	Ansaldo	Iran
	Ardabil	4*159=636	Gas-V94.2	Ansaldo	Iran
	Ghaen	4*159=636	Gas-V94.2	Ansaldo	Iran
	Chabahar	2*159=318	Gas-V94.2	Ansaldo	Iran
IPP projects	Pareh sar	4*162+2*160=968	CC	Siemens	Iran
	S-Isfahan	6*159=954	Gas-V94.2	Ansaldo	Iran
	Tous	6*159=954	Gas-V94.2	Siemens	Iran
	Assaluyeh	6*159=954	Gas-V94.2	Siemens	Iran
	Aliabad	6*162=972	Gas-V94.2	Siemens	Iran
	Fars	6*162=972	Gas-V94.2	Siemens	Iran
	Genaveh	2*162+160=484	Gas-V94.2	Siemens	Iran
Interntaional	Teshrin	2*162+160=484	Gas-V94.2	Siemens	Syria
	Najaf	2*162=324	Gas-V94.2	Siemens	Iraq
	Alsadr	2*162=324	Gas-V94.2	Siemens	Iraq

Table 7-3: Major projects secured in this period

Mapna started as a pure prime contractor of thermal power plant projects in the electricity sector of Iran but evolved into a diversified firm with a presence in several local project markets, the ability to manufacture complex systems, to provide operation and maintenance services for thermal power plants and to sell the electricity. During the fiscal year ending in March 2010, Mapna synchronised 3448 MWs of electricity capacity with Iran's grid which represents 89 percent of all capacities synchronised with the grid in that year (Annual Report, 2009). The firm had a share of 35 percent of the local market for the manufacturing, engineering and maintenance of locomotives for rail and underground purposes. Mapna had also invested fully or partly in over 8000 MWs of power plants, making it the largest private investor in electricity generation in Iran.[9]

[8] This is a steam turbine for the steam cycle of a V94.2 gas turbine plant.
[9] At the time of writing this chapter, 2850 MWs of these investments had been synchronised with the grid.

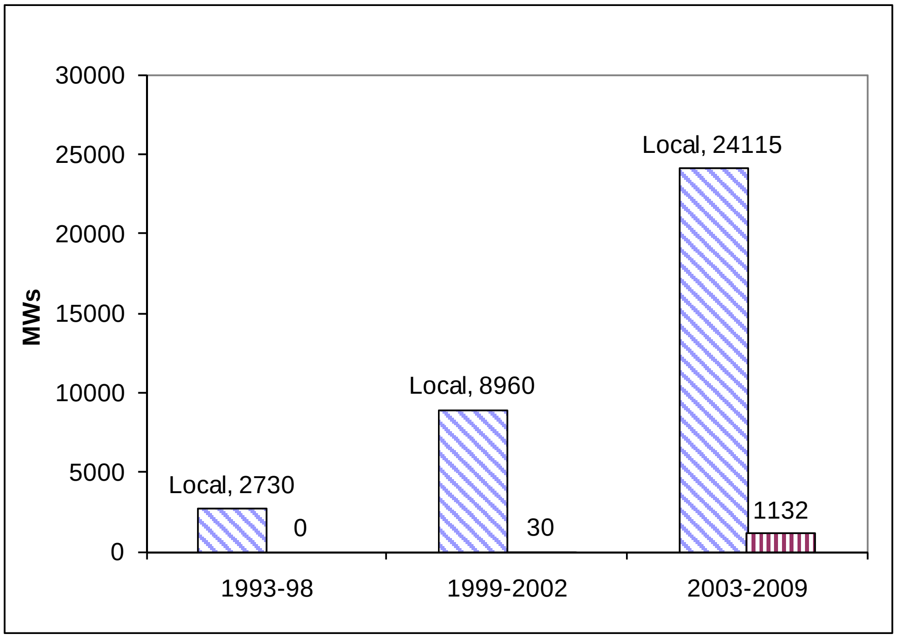

Figure 7-1: Volume of projects secured in each period discussed in this section (Annual Reports of Mapna).

As of March 2010, Mapna fully owned or had a majority share in 30 firms in businesses such as manufacturing, project management, engineering, construction and electricity generation. The product portfolio of the group consisted of gas turbines, steam turbines, generators, boilers, control systems for power plants, turbo compressors, turbine blades, locomotives and some simpler components. As Figure 7-2 shows, annual sales of the company rose from about 0.4 billion dollars in 2002 to an aggregate of 3.1 billion in 2009.

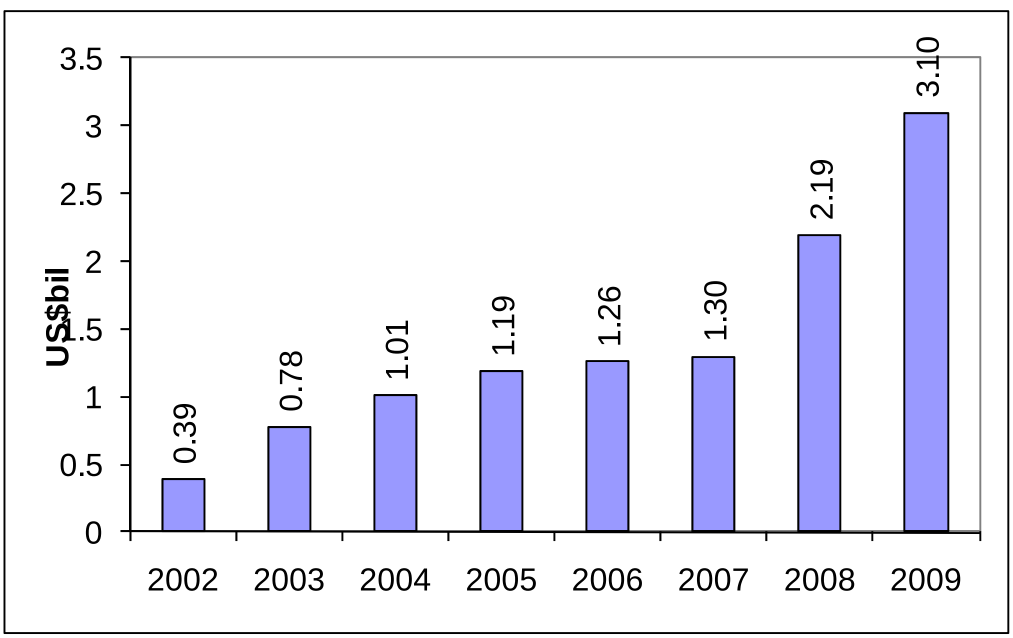

Figure 7-2: Trend of annual sales of Mapna (Annual Reports of Mapna).

As of March 2010, Mapna had 692 full-time employees in its headquarters and 2190 full-time employees in other parts of the group. The 2009 Annual Report of the company claims that, taking into consideration the jobs on project sites and those created by the contractors, the total job positions paid through Mapna in that period reached 20000.

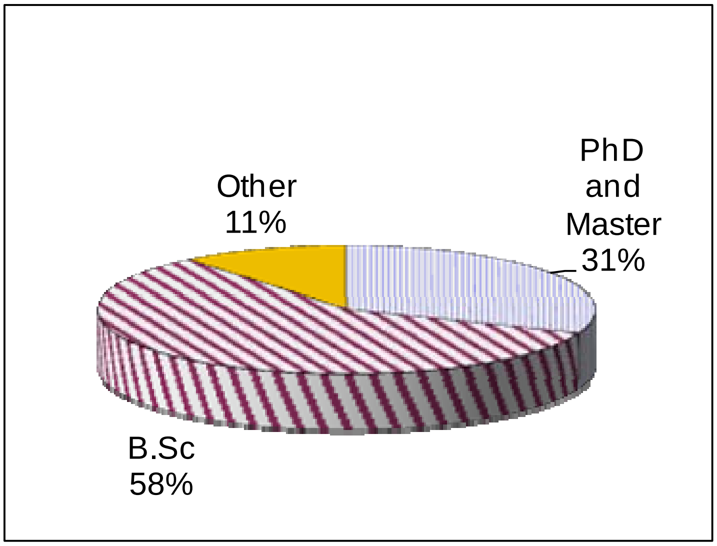

Figure 7-3: Staff with higher education degrees in Mapna headquarters (Annual Report, 2009).

From a wider perspective, as shown by Figure 7-4 , Mapna has synchronised 22904 MWs (equal to 146 power units through 41 separate projects) of generation capacity with Iran's electricity grid since it started business in 1993. In 1999, the year that the first unit was synchronised by Mapna, the total capacity of the grid was 32380 MWs, which means that Mapna has increased the grid capacity by 71 percent throughout its life. For over 60 percent of this new capacity, core equipment was fully or partly manufactured by the firm.[10] However, as the next sections show, the firm has focused primarily on one specific technology of gas turbine and the corresponding equipment in a combined cycle.

[10] This figure is calculated based on the volume of capacities that were synchronised during and after the 30 Gas Units package, excluding those units that were directly bought from Siemens.

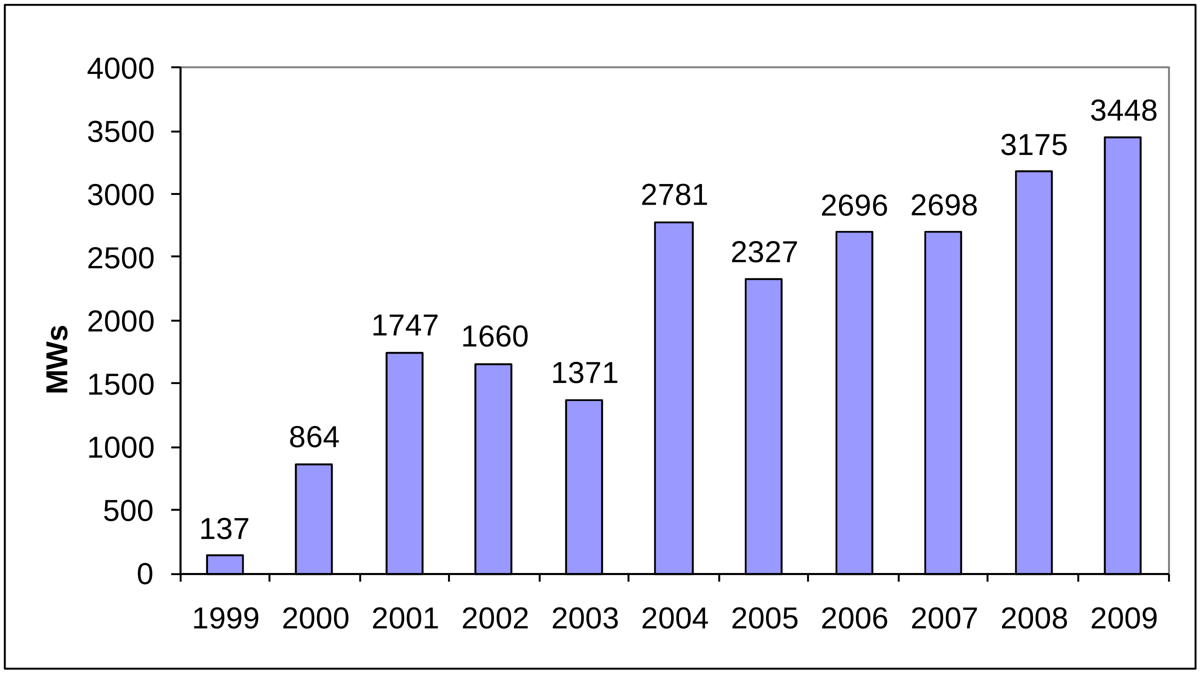

Figure 7-4: Volume of capacity synchronised each year by Mapna (Annual Reports of Mapna).

The following sections investigate the above developments from a latecomer systems integration perspective. The focus is on power plant projects as the firm has a richer history in this field compared to its very recent involvement in locomotive and other energy projects.

7.5 Evolution of LSIC

7.5.1 Latecomer functional SI capability

Engineering and design[11]

In the early years of Mapna, its engineering department was responsible for outsourcing the engineering activities of projects to external firms, interacting with them to produce technical

[11] Engineering and design activities in a power plant can be classified into several interrelated levels. Conceptual design of a thermal power plant specifies the overall characteristics of that plant, including the number of power units, their output, the technology of the turbine and key characteristics of other equipment. This level of design is usually performed by professional consultants or engineering offices within the client organisation. Basic and detailed engineering of thermal power plants largely deals with choosing, specifying and scaling the equipment or systems to realise the conceptual design. Core equipment block engineering, a subset of this task, includes drawing an optimised layout of the core equipment block, specifying cabling/piping/structural requirements, specifying and modifying auxiliaries around the turbine and generator to fit the client's requirements, which is in short called engineering core equipment, and coordinating their interfaces with the rest of the plant. Non-core equipment block engineering consists of specifying other systems that serve the core equipment block and specifying technical characteristics of civil structures such as roads and buildings in a plant. In this context, design review is checking the designs from two general aspects: (1) congruence with the conceptual design of a plant and the criteria of a balanced operation and (2) the possibility of delivering what the designs promise. An analytically different concept is the design of core equipment. This is a more sophisticated design and engineering activity carried out by equipment manufacturers and involves modelling, testing and realising a complex technological system to transform one form of energy to another. The designs have a relatively long lifecycle in this industry. For instance, the V94.2 gas turbine design from Siemens is still being used after 20 years.

documents required by other phases of the project, and reviewing the design documents to ensure that they met the requirements of the contract. At this stage, a large share of the project engineering budget was outsourced to international firms, and local firms took on simpler activities in the detailed design of non-core equipment block equipment, the design of buildings and other civil construction.

To illustrate the point, Ansaldo Energia was responsible for engineering and supply of the equipment for the core equipment block in most of the early projects of Mapna, specifically in the 30 Gas Units package. Its scope of work included the engineering of core equipment (more accurately engineering the auxiliary systems around the turbine and the generator to fit the site conditions and the client's requirements), engineering the layout of core equipment in the building, preparing technical specifications for the building and generating documents for piping and cabling. Ansaldo was also responsible for overseeing the engineering of non-core equipment in the plant. Concurrent with the start of this package, Mapna acquired Monenco Iran, a firm focused on engineering non-core equipment block, in order to increase its role in the engineering of projects.

In 2002, Mapna secured the project for building the utility system of Mobin petrochemical plant. This was Mapna's first experience with a client other than the local client in the electricity sector. The consultant of the new client was only concerned with the basic design of the plant and stayed out of the detailed engineering. Through interactions with this consultant, Mapna learned how to distinguish between basic and detailed engineering activities. The decision of the senior management team was to transfer this practice to projects in the electricity sector. As such, Mapna started internally performing basic engineering for non-core equipment. The Head of the Engineering Department in Mapna recalls the situation in those days:

> "The decision was to carry out basic engineering inside Mapna. Basic engineering was an important part of the overall plant engineering task and previously few firms in Iran had done it... It was not clear to us what was basic engineering; we did not know which documents were basic engineering documents. Some of our colleagues believed that if we copied the detailed engineering documents from previous projects and trimmed some of the details we would have the basic engineering ones. We moved along through trial and error. There was no one to teach us. Our major client in the electricity sector was not familiar with this concept and used to review the detailed engineering documents instead. We gradually learnt what information should be provided as basic engineering and what should not."

Concurrent with the start of the 3000 MW package, the CEO of Mapna asked the Engineering Department to gradually take over the engineering of core equipment from international firms. This request ignited serious debates in the department over the success of the take over. In previous projects, the engineering of the core equipment block and the engineering of core equipment were sourced from a well-known supplier. The core equipment block was therefore treated as a black box to be merely connected to the other systems of the plant. Moving into this area was considered a dangerous leap by conservative engineers. The CEO changed the Head of the Engineering Department, since the former Head believed this leap was unnecessary. The current Head of the Power Block Engineering Unit in Mapna recalls an incident:

> "Engineering and design activities have always been supported and pushed by our CEO... I remember the day that the former Head of Department called for a meeting. He had returned from a meeting with the CEO and told us that the CEO had insisted that we should enter into engineering the core equipment block. He [the Head of Department] was very uncertain about success in this area and sought our opinion. Younger managers were optimistic but the conservative ones condemned the CEO's decision as a gesture to appeal to politicians. However, the CEO replaced the Head of Department and then moved the new Head to another department to force the department to learn the engineering of the core equipment block."

The CEO's aim was to become independent from Ansaldo in the basic engineering of the core equipment block in projects. The basic engineering of the core equipment block correlates with and has interfaces with the engineering of core equipment. The core engine of a particular gas turbine technology can be copied across different projects but some engineering works is required to understand the requirements of the client and the site conditions in each project for customising the auxiliary systems of core equipment.[12] This engineering activity is necessary for defining the specifications of buildings, the piping system and the interfaces of core equipment with the other systems of a plant. Prior to this point, Mapna had relied on leading firms such as Ansaldo for interacting with clients and translating their requirements into the specifications of systems. To take over this task, Mapna and TUGA followed a series of technological activities in collaboration with Ansaldo during the 3000 MWs package.

In the Parand project, the first project in the 3000 MWs package, a consortium was formed between Mapna, TUGA and Ansaldo to carry out engineering of the core equipment block. Ansaldo led the consortium and local engineers took over a small share of the tasks but their

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[12] The core engine was similar in Mapna projects because the client defined project capacities in multiples of 159 or 162 MWs of output.

outputs were reviewed by Ansaldo. In the second project, Urumieh power plant, local engineers took over the overall responsibility and carried out all the engineering tasks but their work was reviewed by Ansaldo. From the third project onwards, Ansaldo had a general supervisory role and replied to technical questions on a demand-basis. Accordingly, Mapna learnt the knowledge of the basic engineering of the core equipment block, including engineering the layouts and engineering core equipment. This knowledge, however, was specific to V94.2 gas turbine technology and to the style of Ansaldo in power plant engineering. The Head of Engineering Department relates the history:

> "Urumieh project was the first time that we were cut off from Ansaldo. We faced an ongoing project. You know, you should face it, speculating about it in advance will not do any good. The project had its own schedule and Ansaldo was not responsible for [producing the] documents. We thought it is easy and we could copy the documents from the first project of the package. We prepared a list of all the documents and asked our manufacturing companies to identify those that they could produce. As a result, some gaps were identified, mostly in areas such as the layout of the core equipment block, piping and cabling systems. We formed a new unit in our department to focus on layout engineering... we did not invent it. In the technology transfer courses of Siemens, we noticed that Siemens has a specific department for layout engineering ... We told our [layout] engineers to copy the documents from the Parand project since major aspects of the two projects, except for the number of power units, were similar. But we asked them to do it intelligently, to understand what is inside. Nothing major happened because the technologies were the same."

Moving to the Siemens approach in engineering the power plants

By the end of the 3000 MWs package, Mapna had acquired a direct license from Siemens to manufacture V94.2 gas turbines. The strategy was to shift the engineering capabilities from Ansaldo's style to Siemens's style to expand the market possibilities. It was initially thought that minimal enhancements would be required. The experience, however, revealed that although Ansaldo was using the core engine of Siemens,[13] it had developed its own style in engineering core equipment.

Tous project, a power plant owned by Mapna, started in 2005 and was Mapna's first attempt to shift to the Siemens style of engineering. Based on the technology transfer agreement, Siemens provided some engineering documents of its Reference Power Plant (RPP), but the main responsibility for layout engineering and engineering of core equipment was on Mapna. Since the transferred documents were not enough for the real engineering tasks, Siemens

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[13] Ansaldo was a licensee of Siemens.

supplied one of its experienced power plant engineers to support the local team in layout and interface engineering. An engineer in Mapna remembers the result of this attempt:

> "We had made terrible mistakes in some cases but eventually we found them and fixed them. For instance, [construction] engineers could not transport the generator into the building because we had designed a very low ceiling. We realised that if Siemens designs have a low ceiling they have a specific method for installing the generator. We did not know this method and thought we could install it using Ansaldo methods like before."

In terms of engineering core equipment, Siemens had provided some specifications and documents, but further support was outside the license contract. Through high-level negotiations of Mapna's CEO, Siemens agreed to provide some detailed documents for engineering core equipment but the documents were almost incomprehensible for local engineers as they had not seen physical examples of this plant. The reluctance of Siemens to provide further support, however, led to a strategic decision to learn from smaller specialised contractors in Europe with experience in supplying engineering services to Siemens and other leading firms. A small engineering company was found in Switzerland which was willing to support Mapna in its learning process. In this cooperation, Mapna found out about other specialised suppliers knowledgeable about the differences of engineering core equipment among the leading firms. These suppliers suggested some alternatives for Mapna. Some of these offers were deployed under the guidance of the Swiss company with the hope of creating a technological distinction in the market. Although several minor problems were revealed during the later stages of the project, Tous project was completed successfully according to its technical requirements.

In the next project, Assaluyeh plant owned by Mapna, the CEO and the senior management team agreed to turn the plant into a test bed for engineers to try various arrangements and designs for the core equipment block to build a distinctive style for Mapna. Some other suggestions were deployed from European specialised suppliers throughout this attempt. The Head of Engineering in TUGA recounts the experience:

> "It was a very courageous move. We were experimenting and in experiments you tend to change things to see what happens. We made a lot of changes, some of them coming out of our inexperience. We had made many things right and had made awful mistakes too. We wanted to be independent ... We tried almost every alternative we could imagine in Assaluyeh ... of course we had to spend on reworks but it was accepted in Mapna that this plant was our learning laboratory ... after all it was our own plant."

Following collaborations with specialised suppliers in six projects, Mapna has built enough confidence and experience to take over the overall responsibility, even though they still get occasional support in some cases from international firms. In particular, the knowledge of the relationships between turbine performance and the capacity of auxiliary systems has been developed through these collaborations and by gathering data from similar power plants around the world. The practice of TUGA was to delegate the detailed design and, in some cases, the manufacturing of turbine auxiliary systems to specialised suppliers in Europe. Facing the growing political uncertainties, the firm has started promoting local contractors in those areas.

Development of Mapna's Standard Design for Gas Power Plants (NIAM)

Customising the auxiliary systems of the turbine and generator is a significant part of power plant engineering. Mapna initially outsourced this task to international firms until the firm started building this capability through trial-and-error learning and collaborating with specialised suppliers, as illustrated in the previous section. Performing such customisations requires time. The weakness of Mapna to perform the engineering quickly enough to respond to the demands of the rapidly growing local market was the driving force behind the development of NIAM.

At the time, changes to the Bill of Material arising from customisation tasks often led to delays in the production of turbines in Mapna's factory.[14] The idea behind NIAM was to compose a standard design of auxiliaries for the turbine so that customisations could be reduced. The Head of Engineering in TUGA speaks about NIAM:

> "Comprehensive engineering for each project was beyond the market demand, project durations were too long for the market ... we had seen a concept in Siemens called EconoPact by which they saved engineering costs through standardisation of auxiliaries and gave some options to the client ... we wanted to be different in the market. We defined a target of completing one power unit in 18 months. It was one of the best records in the world and to achieve that goal we developed the NIAM standard design."

One aspect of customisations is to consider weather conditions in engineering the auxiliaries to prevent the deterioration of performance. Mapna engineers came up with two standard designs to fit the diversity of nature in Iran. However, it was difficult to create a consensus

[14] Trade embargos can create challenges in buying certain materials.

within the firm, let alone to convince the client that these two designs would suffice. A member of the NIAM team says:

> "When NIAM was implemented for the first time, its concept was unfamiliar to [construction] engineers and to operators of the plant. They had made many mistakes in the installation process. They simply did not like to perform it. It took a while to convince them that the design was appropriate but they needed to learn how to implement it ... the first plant was eventually constructed but some major flaws were revealed."

NIAM has been revised three times so far as challenges have appeared during implementation. In preparing the third revision, the CEO of Mapna forced the team to bring in members of the Operation and Maintenance Division to integrate operational perspectives into the design. Currently, Mapna is preparing similar standard designs for combined cycle and steam plants.

Interestingly, transferring the standardisation concept into combined cycle plants has resulted in some innovative concepts. The heat recovery boiler needs to be designed specifically for each project site in combined cycle plants. Through analysis of site conditions in several projects, Mapna's engineers came up with three general designs of boilers that would fit the majority of conditions. Although it is not a product innovation, this new approach to engineering the boiler has been appraised by the licensor of the technology.

NIAM has not only permitted Mapna to realise the goal of completing a power unit in 18 months but has also enabled it to delight its customers in some cases by achieving completion in 16 or 14 months.[15] The advantages of NIAM have, however, come with some side effects. Reducing the customisations has resulted in a lower performance of delivered plants. Although engineers use temporary measures on-site to raise the performance, this approach has led to minor permanent challenges during the operation of plants. This trade-off was attractive to the major client of Mapna in the local electricity sector to respond to the rapidly growing electricity consumption. Other clients in the gas, oil and petrochemical sector, however, prefer fully customised plants. The Head of Engineering in the EMAN[16] division of Mapna says:

> "We borrowed this concept from Siemens and other leading integrators but they still perform a delta engineering in each project which is almost unique for that project. In NIAM, our CEO expected us to create a design that could be used

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[15] This is achieved by the potential of NIAM in speeding up the engineering, procurement and construction activities of projects. Furthermore, NIAM has permitted engineers to standardise buildings in the plant and save time by using similar structures.
[16] After restructuring the group, EMAN division manages the firms that manufacture core equipment of power plants.

with less further engineering ... He asked us to reduce the customisations for moving as close as possible to a mass-manufacturing style for core equipment. Our major client supported this idea although he had his own comments ... but our clients in the oil, gas and petrochemical market have strict requirements and do not give up easily... we face a conflict because our sales department and our CEO expect us to complete every project in 18 months but they seem to forget the prerequisite that is the use of a similar design ... we are technically capable of meeting the specific requirements of each project but achieving 18 months would be difficult if not impossible in those cases."

From a wider perspective, NIAM is gradually degrading an important capability in Mapna. The Head of Engineering in TUGA says:

"We have defined revision periods for NIAM in which we gather feedback from the operation of delivered plants. We have gained a very important capability, which is to accomplish a large number of projects in a short duration, but it has taken away one thing, which is the power to modify and to implement changes in every case; it has weakened us very much ... the market will not stay like this in the course of the next four years ... as we progress over time we will lose this big advantage. We are at a point that we can finish projects in 14 months, permitted by mass production of core equipment ... Our current advantages for growth will harm us in the future, we will have to modify plants, to change the sourcing strategy..."

EMAN division coordinated the collective effort of several engineering units across Mapna to prepare and revise NIAM. After the corporate restructuring, this division also became responsible for exploring the standardisation possibilities for other systems of plants.

Investment in understanding the behaviour of a turbine

Since Mapna started full manufacturing of gas turbines in 2005,[17] the overwhelming load of project activities and also the reliance on licensor support has not allowed for reflection on the importance of investments in understanding turbine behaviour. Although local engineers dealt with technical problems during the installation and operation of plants, they sent back the description and related data in complex cases to Siemens for analysis. The Head of Engineering in TUGA says:

"We expressed the need to perform these analyses internally three or four years ago but our CEO insisted that it is not necessary considering our resources and the amount of work we have in projects. Actually, he would have questioned me if I had allocated resources for those activities."

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[17] According to the scope of the technology transfer agreement.

However, some new developments built a commitment for investing in modelling and analysing capabilities. The manufacturer of the heat recovery boiler in Mapna requires technical specifications of the flow of turbine exhaust in each project site for customising the boiler. On previous occasions, TUGA outsourced this task to a local firm but gradually realised that it was a major part of the firm's knowledge base that should not be outsourced. Meanwhile, certain unexpected challenges emerged during the operation life of delivered turbines, some of which were fundamental design issues that Siemens is trying to resolve in its future versions. Turbines are, however, guaranteed by Mapna and resolving the challenges is not covered in the license agreement with Siemens. An engineer in Production Engineering Department of TUGA says:

> "We struck a dead-end. Our trial and error approach was not effective and nobody helped us. We realised how important this weakness was ... there was a meeting and our CEO insisted that we should allocate resources for understanding the behaviour of our turbines. This was late, very late."

TUGA started to analyse its own turbines in early 2009. In January 2010, 72 engineers were working in the Production Engineering Department of TUGA and spent around 30 percent of their time engaging with modelling and analysis tasks. The plan was to increase the commitment to 60 percent of available resources in the department. A specific unit was created very recently in the Production Engineering Department of TUGA for the analysis of turbine behaviour. Some sections of the turbine, such as the rotor and the exhaust flow are already modelled by this unit to resolve emerging behaviours during the operation of the delivered plants.

In another development, Mapna participated in the competition for a project in the local oil, gas and petrochemical market in which a gas turbine was required to operate under a different pressure compared to the design level. Siemens concluded that it was theoretically possible, although the firm had not yet experienced it with V94.2 gas turbines. Based on this comment, the client and Mapna went on to carry out the project. Siemens promised to support the related engineering tasks but had to withdraw from the project amidst new trade embargos. Engineers needed to build a model of the turbine and analyse its response to the dynamics of the electricity grid. A team was assembled from TUGA, Monenco Iran and some local research centres to build this model. The team was lucky that unexpected behaviours emerged in two project sites and they could gather data for validating their model. Although some minor modifications were eventually implemented on the site, the project was completed to the client's satisfaction. This success built a high level of self-confidence among managers and has opened up new market possibilities in using existing turbines for new applications.

Establishing R&D departments

An outcome of the restructuring of Mapna in 2006 was the establishment of R&D departments across Mapna. It was concluded that achieving the firm's vision implied a serious attention to the creation and development of technological capabilities. As the evidence shows, the main objectives of R&D in turbines were to get a better grip on the knowledge underlying the existing turbine technology in Mapna, to resolve emerging challenges in delivered plants and to expand market possibilities. In line with these internal aspirations, the Ministry of Energy also supported building deeper knowledge of turbines in the face of possible wider trade embargos in the future. Mapna has therefore defined a big project called National Turbine to attract funding for organising an R&D team for turbines. The Head of the R&D in TUGA says:

> "We do not aim to establish a turbine design office here and accept orders for designing turbines with various outputs. Our aim is to bring design knowledge into the firm to the extent that we can understand our own turbines better than we do now, to become capable of upgrading them, to become capable of designing some sections of a turbine. Accepting orders for designing new gas turbines is a massive objective and we do not think we can realise it in the next 20 years."

In January 2010, the R&D Department of TUGA had 14 researchers chosen from among candidates with a research background in understanding and improving turbines in the local aviation industry[18] or other related sectors. The firm aimed to double its R&D staffing by the end of 2010. Mapna has also contributed to establishing a turbine research centre in Tehran University and is building a state of the art laboratory and test facility in TUGA.

Since its establishment in 2009, the R&D Department in TUGA has followed multiple objectives. In particular, the team has focused on understanding the current turbine by building dynamic models of different sub-systems of a turbine. Although a preliminary understanding has been created through these efforts, laboratory data is required to validate this knowledge. In the absence of such data, engineers have gathered approximate data from operating power plants and the outputs of their research is being published in international engineering journals.

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[18] Aviation turbines have similarities to and also important differences from gas turbines. Embargos on Iran's aviation industry started in the 1990s, preventing the country from purchasing new engines and spare parts. It led to the creation of local capabilities in the maintenance and modification of turbines.

Parallel to building some fundamental attributes for turbine design, the R&D Department has defined other research projects with more concrete outputs. One particular project aims to upgrade the existing V94.2 gas turbine to increase its output power and efficiency level without altering its physical dimensions. This project seeks support from a foreign consultancy and is expected to finish by the middle of 2011. If it is successful, Mapna will implement these modifications in existing plants.

The most significant project in terms of expected outcome, however, is National Turbine. This would result in a gas turbine with a medium level of output and is anticipated to build a good market in the local oil, gas and petrochemical sector and distributed generation of electricity. Turbine design is a complex process, involving different areas of technological knowledge, various tests and several decision points to choose from a range of peripheral technologies such as sealing and coating technologies. Although a general knowledge of this process exists in the firm, TUGA's engineers believe that they are unaware of many of its aspects. The National Turbine project is expected to overcome this gap. In particular, it aims to undertake the design process from start to end under the supervision of an international designer to build knowledge on organisation, the principles of design, alternative technologies and the range of test facilities that are required in design. Even though Mapna prefers to accumulate these attributes through international collaborations, alternative internal routes are also being considered in the face of trade embargos. The Head of R&D in TUGA says:

> "This [National Turbine project] will also increase our knowledge about our own turbines. We will be able to analyse more accurately the problems that occur during the operation of our turbines... we want to upgrade our knowledge. If this [turbine project] turns us into a designer we will certainly accept orders in the future; if not at least we will be able to analyse our turbines with more confidence. There is a whole world of new opportunities in this country if we only enhance our knowledge a bit in this area."

Although the widening of trade embargos may pose challenges to design tasks,[19] Mapna is determined to accumulate knowledge through every possible means and has allocated a specific budget for this purpose. More importantly, the self-confidence of engineers in modifying turbines has improved as a result of current technological progress such as development of NIAM and some modelling activities. The Head of R&D in TUGA was responsible for some modifications in aviation turbines before joining Mapna. He says:

[19] The embargos can even affect the sourcing of a range of peripheral technologies such as the sealing and coating that turbine designers use.

> "When I was in the aviation industry, we modified many engines courageously and put them into operation very carefully ... here we face oppositions against these changes everywhere because possible mistakes are thought to be very disastrous. These speculations have degraded the confidence of engineers in Mapna. People [in Mapna] have always sought a reference or an approval from a leading firm for modifications."

The new organization as a holding has enabled the Sales Department and the O&M Division to reflect on product improvement opportunities. The central R&D Department screens these ideas and defines appropriate R&D projects. For instance, a project has recently been defined to modify the existing turbine for burning gasoline in addition to natural gas. Parallel developments are also being pursued in other Mapna manufacturing companies to substitute some materials or to build required machinery locally to cope with the increasing embargos.

Whether the aspirations of Mapna to build the capabilities of turbine design will succeed or not is a matter of time. The following quote from the Head of the Engineering Department in EMAN reflects impressions that were observed throughout the fieldwork:

> "We should design the national turbine, we should increase our knowledge of turbine design to suggest modifications. Like the case of core equipment block engineering, until five years ago nobody had dared to approach it but now it has become very ordinary for us. Turbine design is now like core equipment block engineering five years ago."

Manufacturing

As was described in the first section of this chapter, Mapna has diversified into manufacturing core equipment for gas and combined cycle plants. In this section, we investigate the case of turbine as an almost similar approach has been followed in other cases.

Mapna followed a strategy of mixing purchase contracts with technology transfer agreements to realise the client's objectives in the 30 Gas Units package. Mapna organised an international competition to procure the equipment for all the projects of this package on the condition of gradual transfer of manufacturing knowledge to local firms. Ansaldo Energia, a licensee of Siemens, won the contest for transferring the V94.2 gas turbine and the compatible generator.

Several components were outside the scope of the agreement due to the economic infeasibility of their local production.[20] Local production started with simpler auxiliary systems and progressively moved towards the core components. Mapna acted as a coordinator in transferring the knowledge of auxiliary systems to Iranian firms. For core components, however, Mapna established a new firm called TUGA. Although the local production of auxiliary systems started from the first unit in this package, a gradual plan was designed for the core components of the turbine. Out of 30 units, the core components for the first six units were fully supplied by Ansaldo. The next five units were only assembled in TUGA. From the 12th unit, TUGA started manufacturing the components gradually from the simpler ones to the most complex one, the turbine rotor. From the 20th unit, all turbine components were manufactured and assembled in TUGA, except for the parts described above, to the full extent of the agreement. The first turbine fully manufactured by TUGA was shipped to the project site in 2005.

TUGA deployed sources other than the license documents to learn the precision manufacturing processes of the turbine. Iranian technicians and engineers resided in Ansaldo's factory in Italy for some time during which they received training and supervisory services from expert technicians. Ansaldo also supplied technicians to supervise Iranian technicians on their return to Iran. Machinery and manufacturing tools were purchased and in some cases modified according to Ansaldo's suggestions. TUGA implemented the quality assurance system of Ansaldo and learned about specialised suppliers of material and components in Europe.

TUGA has continued manufacturing gas turbines from the end of that contract without foreign help. Recently, the firm celebrated the delivery of its 100th gas turbine. Although TUGA received good support from Ansaldo throughout the contract, local engineers had to customise the transferred manufacturing procedures to fit local conditions. This engineering capability was also required in the production stages where deviations arose in specifications and materials.

In line with the market strategies of Mapna, TUGA acquired a direct license from Siemens in 2006.[21] The license was for a newer version of a turbine that Siemens itself was still

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[20] Auxiliary systems outside the contract included fuel oil, fuel gas and turbine fire fighting systems. The blades of the high temperature section were not included in the agreement because the relevant technology was owned by a third party.

[21] As was discussed previously, turbine blades were outside the original technology transfer. Mapna started manufacturing turbine blades in 2002 but the license for high-temperature blades was acquired in 2007 from Doncaster.

implementing in its first cases. As challenges emerged in new Siemens plants, TUGA had to revise its processes to fit with the modifications suggested by Siemens.

Over the years, TUGA has expanded its product portfolio. Currently, it manufactures 25MW gas turbines under a license from a Ukrainian firm and 160MW steam turbines under a separate license from Siemens.[22] The capabilities for engineering the manufacturing processes have developed over time along with other manufacturing capabilities. The Head of Engineering in TUGA says:

> "The first technology transfer process took a long time. We tried to use the same machinery Ansaldo suggested or to get support from them to adapt our own tools ... In the next experience, we just had brief visits to the foreign workshop and resolved the consequent [manufacturing] problems ourselves ... For instance, in the case of Ukraine, they were not familiar with our advanced machinery so we could not use their processes... we took the start and finish points and translated the process into our own technology."

This section has described the evolution of manufacturing capabilities in TUGA. The related subject of engineering core equipment was discussed in the previous section.[23]

Analysis and interpretation

At the outset, Mapna focused on project management and outsourced the engineering tasks of projects to renowned international firms. Realising the significance of these tasks in the overall management of the projects and the prospects of a growing local market led to acquiring a local engineering firm, six years after Mapna was established. Mapna realised the differences between basic engineering and detailed engineering of power plants through working for a client in the local oil and gas market. This knowledge was built through trial-and-error learning and interacting with the client. Mapna decided to carry out basic engineering of non-core equipment (non-core equipment block) internally and leave the detailed engineering to other firms. A few years later, the CEO forced the Engineering Department to take over the basic design of the core equipment block and the engineering of core equipment from international firms.

The attributes underlying the engineering of core equipment and layout engineering of the core equipment block were built gradually through the 3000 MW package in which Mapna

[22] These versions of gas and steam turbines were still in the product portfolio of Siemens at the time of writing this chapter.
[23] Mapna bought core equipment block engineering services from Ansaldo throughout the technology transfer agreement.

received support and supervision services from Ansaldo Energia. After some time, the firm switched to the Siemens approach in the engineering of power plants for expanding market opportunities. This change of capabilities took place over two projects and through the use of license documents from Siemens, trial-and-error learning, the supervision of a skilled engineer from Siemens, and most importantly through learning from some European specialised suppliers. Backed by the senior management team, local engineers tried several alternatives in a new power plant owned by Mapna for building a distinctive (slightly different) approach for Mapna in the engineering and arrangement of the core equipment block.

Building on its experience, Mapna developed a standard design for its gas power plants (called NIAM) in which the need for customisations on every project site had been minimised. The development of NIAM was pushed by the CEO to achieve world class records in project completion times and to reduce manufacturing times of turbines by transforming them into a mass-production style. Although NIAM allowed for the achievement of shorter completion times in projects, it has caused some problems during the operation of plants, and the neglect of investments in customisation capabilities may create limitations in competitive markets.

Challenges posed by emerging behaviours of turbines in the delivered plants primarily motivated Mapna to break its reliance on the licensor and start modelling and analysing existing turbines. In another technological attempt, engineering the existing V94.2 gas turbine for a new application was carried out in collaboration with local research centres. This attempt increased the self-confidence of engineers and opened up new market possibilities.

In line with Mapna's new strategies, R&D departments have recently been established across the firm to enhance technological capabilities and create market advantages by improving products and technologies. For instance, the existing turbine is under modification with the help of a foreign consultant to increase its efficiency and output. In a separate project, the firm aims to design a middle-class turbine and go through the design process from start to finish under the supervision of an experienced designer to build some knowledge elements that will help the firm understand its existing turbines better.

As Figure 7-5 indicates, Mapna started building the basic and intermediate levels of latecomer functional SI capabilities relatively late compared to other constituent parts of LSIC, around 15 years after the firm was established. Since then, Mapna has moved up the ladder rapidly, compared to Farab, by accumulating the basic innovative level and simultaneously investing in the intermediate level. Until a few years ago, the firm was reliant on foreign suppliers even to translate clients' requirements into specifications of core equipment and the layout of the core equipment block in its projects.

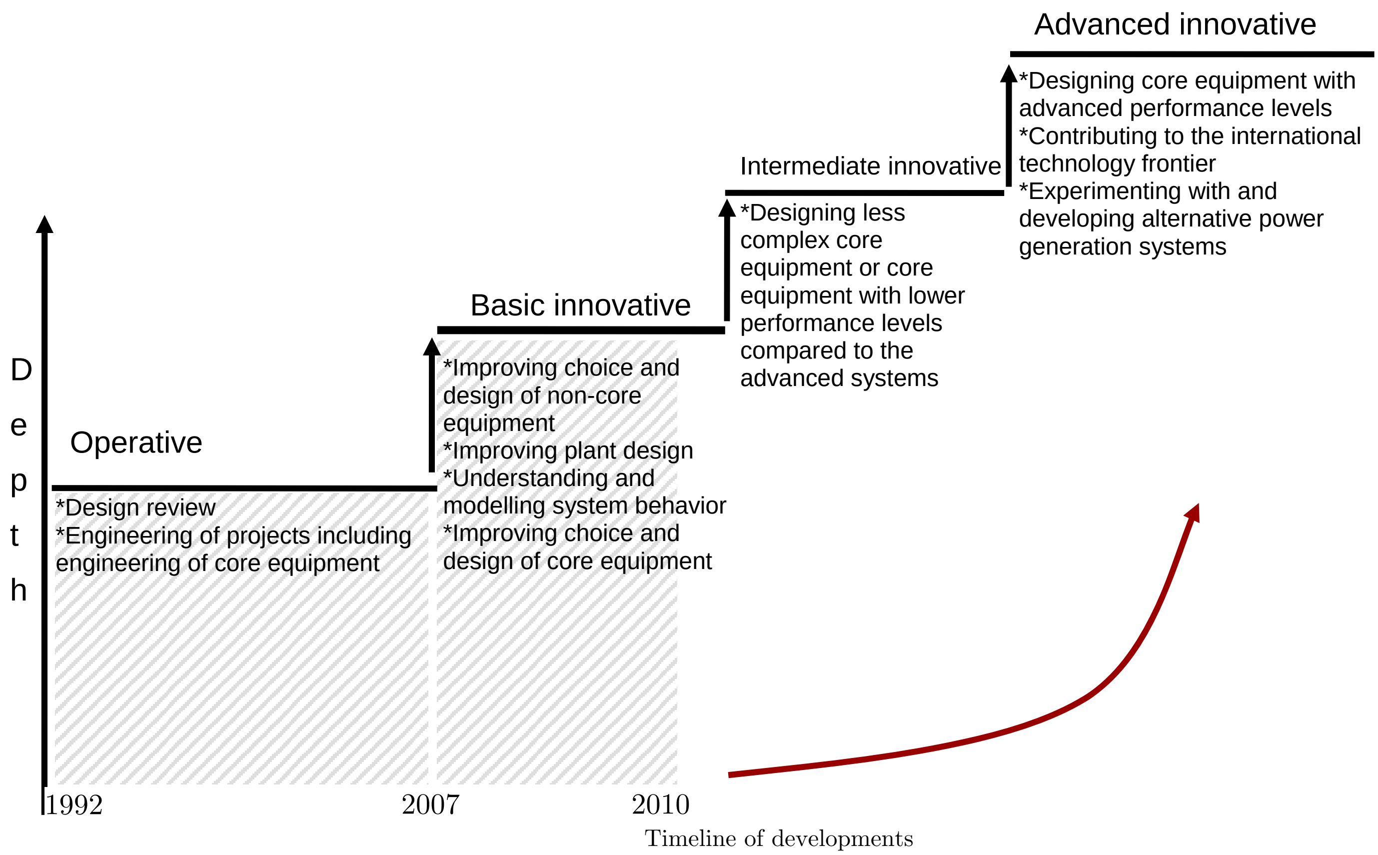

Figure 7-5: the evolution of latecomer functional SI capability in Mapna.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

7.5.2 Latecomer project SI capabilities

At the outset, Mapna hired key members of its project teams from among candidates who had experience in local power plant projects or other industrial projects. In terms of project management processes and organisation, the CEO of Mapna believed that the country could not afford to waste time on trial-and-error learning. Accordingly, a training/consultancy contract was signed with Monenco Agra Canada, an internationally well-known engineering and consultancy firm in the power plant industry, to transfer project management knowledge and to organise Mapna according to the latest practices.

The consultancy package of Monenco included a project management methodology, workflow of interactions among functional departments, a coding structure for project tasks, processes for project control, software specifically developed by Monenco for the project management of power plants, a database for storing project information and technical documents, and finally training and consultancy for implementing the above components within Mapna. These attributes formed a starting basis for project management in Mapna but the firm improved upon them by managing an increasing number of projects and in its relationships with leading firms. Concurrent with the increase in the number of projects and Mapna's diversification into other project markets, Mapna invested in developing an integrated enterprise software named Mapna Total Solution (MTS), including several modules such as project management and management of documents.

As discussed in the previous section, Ansaldo Energia won the international competition in 1998 to transfer manufacturing knowledge of core equipment to Mapna. Although it was not formally included in this contract, Mapna improved upon its project management knowledge through the interactions that took place in this partnership. In 2003, Mapna signed another longer-term cooperation contract with Siemens, consisting of knowledge transfer in power plant engineering. A part of this arrangement was for Siemens to organise workshops to educate Iranian employees on engineering topics, project management methodology and Siemens's organisation for projects. However, by this time, Mapna had gradually built its own version of project management. This opportunity was used to benchmark its practice against Siemens. A member of the Project Planning Department in Mapna Development II Company (MD2) says:

> "Monenco Agra Canada gave us some bases for the project management of combined cycle plants including the software and a methodology. These were bases upon which Mapna built its own mechanisms, although we learned parts of them [the mechanisms], but not in a classic way, from Ansaldo and Siemens later. Siemens organised specific workshops for us about project management but the workshops just familiarised us [with Siemens's approach]. Mapna has built its own mechanisms."

Mapna initially adopted a matrix structure in which a functional department was responsible for managing the engineering tasks for all phases of projects, another department was responsible for procurement of core equipment[24] for projects and a final one dealt with central planning and control of projects. In this structure, project teams followed up project tasks in functional departments, interacted with clients and contractors and managed day-to-day activities on project sites. Each project team suggested a budget at the start of its project.

[24] Namely the turbine, generator, HRSG boilers, parts of the cooling system and high-voltage transformers.

This project budget was examined by the Central Planning Department and finally approved by the CEO to become the basis for monthly project (time and cost) controls by the Central Planning Department.[25] A member of the Project Planning Department in MD2 says:

> "Using MTS for time and cost control in projects started from the 22 CC package but we controlled the previous projects using other mechanisms. In fact, it has always been important for us to have accurate measures of cost and time in projects ... initially we used Monenco's system and then shifted to MTS ... most important of all is that we have always believed that the cost and time of project tasks should be controlled to explore improvement opportunities. Mapna really cares about this."

Every project in Mapna has an execution strategy which specifies into how many packages the project tasks should be classified and chooses the procurement strategy for each package.[26] From Mapna's early days, project strategy has been discussed separately for every single project by the senior management team. At the beginning, the strategy was to focus on the project management of power plants and to outsource other tasks to specialised engineering, manufacturing and construction contractors.

In the first projects, the detailed engineering of projects including engineering of the core and non-core equipment was outsourced and Mapna only reviewed the outputs. Initial contractors were mainly foreign but Mapna helped local firms to upgrade their capabilities by promoting cooperation between them and international suppliers. The technology transfer programmes were initially in the non-core equipment of the projects but were expanded to core equipment in later stages. Over time, Mapna took over the basic engineering of the core equipment block, the engineering of core equipment and non-core equipment block, and outsourced the detailed engineering tasks.

The prospects of a large and protected local market[27] to respond to the rapidly growing electricity consumption in the country was a major motivation behind Mapna's decision to vertically integrate across the value chain in the late 1990s. It acquired manufacturing and engineering firms in order to reduce risks in the management of projects and to increase the share of the firm of value added in projects.[28] The acquisition of existing local firms and the establishment of new ones continued until Mapna gained managerial control over the supply

[25] As will be discussed later, the same arrangement is in use today but the location of responsible units has changed in the new structure.
[26] For instance, a project can be managed through 13 work packages, of which a number are outsourced based on an EPC strategy and others on EP or C strategies.
[27] Mapna enjoyed a protected local market in the first 15 years of its existence.
[28] Since the 1979 Islamic Revolution, Iran has continually faced the threat of wider trade embargos. Businessmen and policy makers are motivated to decrease the level of their dependence on international firms in infrastructure projects.

of core equipment in power plants. This strategy proved to be successful later in reducing risks and expanding Mapna's market possibilities. This point will be discussed further in the section on NIAM.

Vertical integration in the manufacturing of core equipment, engineering and erection of power plants increased the complexity of management in the expanded organisation. On the other hand, the business environment had changed since 1992. The new government policy was to encourage private investments in power plants and there was no guarantee that new clients would choose Mapna over foreign firms. Some local competitors had also risen in the local electricity market. Primarily in response to these developments, Mapna went through a restructuring programme entitled 'Restructuring Mapna Group: Preparation for Growth'.[29] At the end of this restructuring, Mapna adopted a holding structure with six business divisions and a number of service units.

In this structure, one division (the EPC division) was responsible for contracting power plant projects. Three EPC companies were established under this division: Mapna Development 1 (for gas powered plants), Mapna Development 2 (for combined cycle plants) and Mapna Development 3 (for customised plants). This division also controls Monenco (engineering) and Nasbniroo (erection and construction) companies. The aim was to bring all the resources for managing a power plant project under one umbrella. Another division (EMAN division) is responsible for engineering and manufacturing core equipment in projects. All the manufacturing factories of Mapna are organised under this division. A new division was also created (the O&M division) to focus on operation and maintenance services of power plants and to generate feedback to the EMAN and EPC divisions.

Within the new structure, project tasks are divided across divisions and their underlying firms. The execution strategy of each project is discussed and approved within a high-ranking committee chaired by the CEO of Mapna. A similar approach is deployed for controlling projects in which the projects are controlled by the Planning Department Unit of each EPC firm and, at a higher level, by the Planning Department of the EPC division. The EPC division endeavours to promote uniform and modern project management methodologies in its underlying firms. Although this division manages projects through constant interactions with other divisions and departments of Mapna, allocation of financial resources among projects is finalised by the CEO of Mapna.

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[29] More information about this restructuring is provided in the section on latecomer strategic SI capabilities.

In terms of procurement, there is a divided scope of supply within the group. The Central Procurement Department in Mapna is concerned with supplying core equipment for projects.[30] Although the policy of Mapna is to participate in those projects in which it can sell its own core equipment, some clients may require external equipment. The procurement of non-core equipment, however, is delegated to the responsible development company, although they have to use a central database of suppliers/contractors which is maintained by the central department.

Similarly, the engineering tasks of projects are scattered widely around Mapna. Basic engineering of the core equipment block is performed by the EMAN division, including layout design, basic design of civil structures and piping/cabling systems. Further engineering activities for core equipment are performed by underlying manufacturing firms. However, the management of basic engineering for non-core equipment is delegated to Mapna's EPC firms. Both the EMAN and EPC divisions buy some engineering services from Monenco Iran, mostly in the areas of civil engineering and non-core equipment block engineering. The Engineering Unit of EMAN, however, holds the responsibility of improving the engineering capabilities across the holding.

The organisation of project teams has not, however, changed significantly in the new structure. Every project team employs three people for planning and control activities and every EPC firm employs about 20 permanent people for central planning and control of its projects. Following this mix of centralised and decentralised systems, Mapna is able to identify and implement improvements continuously. A member of the Planning Department in MD2 says:

> "As our experience increases in planning and controlling projects, we modify the project plans, modify the relationship among activities [and] modify the duration of tasks. [We] improve the controlling mechanisms, change our methods [and] change the strategies of projects. [We] convene regular meetings to discuss the weaknesses and strengths of our practice."

Diversifications into new project markets since 2004 and opportunities provided by the new structure of the firm have prompted a new phase of enhancing latecomer project SI capabilities in Mapna. New customers in overseas markets require senior project members to have international certificates such as PMP. They also ask for project procedures to be based

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[30] Depending on the conditions, this department sometimes also buys the equipment for cooling towers.

on international project management guidelines and stress the importance of short times to finish the projects. Although Mapna has used its own project management procedures for a relatively long time, which seemed to be enough in the past, it has started to translate them into the language of international project guidelines. This attempt has revealed a number of gaps. For instance, new processes are being developed for the closing phase of projects, including a new format for reporting lessons that can be deployed in other projects. This report simultaneously works as an assessment of the collective effort of all divisions in successful completion of the project. This report is discussed in a widely participated event in the holding to identify improvement opportunities. The Head of the Project Planning Department in the EPC division says:

> "In tenders, they ask for [our] project methodology. Fortunately, we have documented many parts of our methodology. Before the PMBOK became so popular we were only asked to provide our project execution plan. But now we are transforming this into the PMBOK language so that everybody can understand it."

The EPC division recently organised formal training programmes for 60 members of the project teams across the division to acquire PMP certificates. The division has also planned to complete the implementation of a new project management methodology, which has been prepared based on the PMBOK guidelines. The independent legal identities of EPC firms encourages them to closely control cost and time of their projects. Parallel improvements in project management are therefore ongoing in Mapna, in each division and its underlying firms. For instance, EPC companies participate independently in the national EFQM and Project Management awards and the three EPC companies have also been assessed against the OPM3[31] standard.

Through the assessments for awards, a number of improvements in project management systems are underway in these firms. For instance, MD2 has organised a PMP training programme for a large number of its personnel and is implementing some other changes in its project management systems such as implementing a new computer application for sharing knowledge among its projects. Two projects of this firm were awarded the national certificate for project management in a tough competition organised by the Iranian Society for Project Management.

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[31] Organizational Project Management Maturity Model (OPM3) is developed by PMI. PMI describes it as the global best practice standard for enterprise improvement in project firms.

In addition to the above improvements in project capabilities, a new division of labour in the holding has created some organisational resources to reflect on higher-impact improvements. The CEO of the group has pushed for the development of Mapna's Standard Design for Gas-Fired Power Plants, abbreviated to NIAM. Detailed technical discussions about NIAM have been provided in the previous section. Under the new division of labour, the EMAN division is responsible for the standardisation of engineering tasks in projects and reducing the diversity of equipment in projects. NIAM was developed by this division in close interaction with manufacturing firms in 2006. Currently, engineers are developing a similar standard design for combined-cycle plants.

NIAM enabled Mapna to achieve the record of completing one power unit in 18 months. This is close to the practice of leading systems integrators. In some cases, Mapna has even delighted its clients by finishing projects earlier than scheduled, in 16 or 14 months. The standard design has also enabled Mapna's EPC firms to increase the efficiency of project construction activities through using pre-built, standardised civil structures. For instance, one EPC firm has recently been awarded a package of eight projects that needs to be finished quickly. Using a similar technical specification for the main buildings, the firm has ordered eight similar structures to be built and installed quickly on the project sites. Although using the same specification means that buildings are overdesigned to cope with the worst conditions and so are unnecessarily expensive in some cases, the initiative has enabled the firm to meet tight schedules. The shortcomings of NIAM and its effects on other LSIC components have been discussed in the previous section.

As another example of far reaching initiatives, the CEO of Mapna defines challenging completion times for projects as an internal objective, earlier than the contractual deadline. The aim is to provide incentives inside the group to enhance project capabilities and reach the best in class norms.[32] This initiative allows for latent challenges between departments, in terms of project interactions, to surface and be transparently discussed.

The new division of labour in Mapna has also resulted in a separation of responsibilities for routine and innovative activities. EPC firms have focused on reducing the time and cost of projects. By reflecting on the practices of GE and Siemens, EPC firms have deployed pre-built and pre-tested concepts to reduce delays in the erection and commissioning of non-core equipment in projects. For instance, firefighting pumps are assembled and tested on the

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[32] Normally, these internal goals are benchmarked from Siemens.

manufacturer's site and installed on appropriate structures before shipment to project sites. Similarly, control systems are pre-installed in a cabin and shipped to the project site which, among other things, reduces the need to construct buildings to house them.

Overall, Mapna has an acceptable record in project management. Over the last five years, Mapna has synchronised around 14500MWs of power plants, which is quite an impressive performance for a young firm.[33] By deploying the above project strategies, the firm has been able to keep up with the speed of growth in local demand and has nearly doubled the power generation capacity of the country since its establishment (Annual Report, 2009).

In terms of project management measures, the actual time of project completion in relation to the contractual time was 1.02 on average across all projects in 2009, but Mapna has planned to reduce it to 1 by 2013. Although the firm has realised competitive times of 18 months or less in its recent projects, these achievements were made possible using NIAM and by considerable reductions in customization and engineering activities of core equipment. In this sense, the firm is still behind leading systems integrators who achieve the same time records despite performing some engineering tasks to customise each plant to the customer's requirements. Using the standard design has also slowed down the development of customisation capabilities. The current advantage may turn into a disadvantage in the future, when meeting each client's requirements may become a rule of the game even in the local market.

The firm recently completed a project in Syria two months earlier than the contract schedule. The CEO of Mapna discussed the performance of the project with the client on a visit. The Head of the Engineering Department in Mapna describes the CEO's impression on his return to Iran:

> "Our CEO visited the Teshrin project site. The Syrians had told him, this is a good view somebody is looking from the outside, they had told him that your performance is good from many aspects, your equipment is good, your speed is good, you keep up with the schedule but you are a bit confused in engineering activities. Surely, we [Mapna] have done the engineering properly from a technical perspective, in that we have completed the project successfully but our engineering workflow is not smooth. When you aim to synchronise a plant [with the electricity grid] in 18 months with all the novel information and requirements of a foreign client you can imagine how much information needs to flow across the holding structure to finish engineering tasks in seven to eight months ... We have

[33] Siemens, as a leading firm in this market and with over 100 years of experience, has synchronized 30000 MWs over a five-year period (Siemens Power Catalogue, 2009).

> invested less in these areas so far. I think these are more management issues [rather than technical]; we are behind Siemens in these areas ... The CEO appointed a group of his deputies to find a solution for this weakness. The current process reengineering initiative in Mapna is towards this aim ... Now that we have a standard power plant we want to standardise our workflows ... For instance Siemens has a standard called RDP which means Reference Design Process. But we do not have it. Actually, the lack of such standards creates frustrations among our colleagues in work."

Pre-project

The Ministry of Energy awarded the first project to Mapna under no competition. Later in 1996, Mapna was asked to offer a price for securing the 6 CC package,[34] leading to the formation of initial estimation capabilities in Mapna. At that time, the firm did not have a rich background in project management and its estimations were rough, largely based on rules of thumb calculations. The firm took part in its first overseas competition in Oman in 1999. The project was a small 40 MWs gas-fired power plant. Since there was no sales department in Mapna, the Procurement Department prepared a proposal in collaboration with the Engineering Department. Mapna won this project even though its estimations were still based on rules of thumb.

In 2001, Mapna participated in the competition for the Mobin utility project in the local petrochemical sector. This was the first time that Mapna was not able to enjoy the protection of its traditional local electricity market. To increase its chances of success, the Engineering Department prepared a detailed technical specification for buildings and some non-core equipment of the project to make the estimations more accurate. These specifications were improved over time as Mapna accumulated experience in project management, resulting in the creation of a database for estimations that is still in use.

Mapna enjoyed a protected, monopoly position in the growing local electricity market until 2004. The firm secured the 30 Gas Units and the 22 CC project packages, which were very significant to the growth of LSIC in Mapna, on a price offer basis. The entrance of private investors into the local market and the rise of local competitors, however, forced Mapna in 2004 to prepare for serious competition. The Head of the Sales Unit in Mapna says:

> "Mapna had a mechanism for producing estimations from the start but its enhancement was driven by market needs. At that time, Mapna had [enough]

[34] The client needed this offer to justify higher governmental bodies that prices were better than or equal to running a competition.

> projects; in fact it was overwhelmed by projects and so [the firm] did not feel that it needed a significant mechanism for competitions ... The Sales Department was created later ... we won the Mobin project while there was [yet] no Sales Department in Mapna."

Some ideas for designing bid processes in Mapna were developed through working with Ansaldo Energia under the technology transfer agreement. The Sales Department of Mapna acquired some other concepts through the knowledge transfer courses of Siemens, described above, leading to building a formal process for proposal preparation. This was an integrated process involving 11 departments and units across Mapna and deploying various committees to discuss the 'go' or 'no-go' decisions, prices and technical suggestions for every bid. The process is being continuously improved by analysing the failures and successes. For instance, inaccurate estimations in one bid and the consequent financial problems led to modifying the process to allow a wider participation of EPC firms and project teams in the preparation of bids.

The reorganisation of Mapna marks a new phase of developments in its pre-bid and bid capabilities. Separate units were created in Mapna to carry out strategic marketing and operational marketing tasks. The former unit gathers strategic intelligence on markets and competitors, and suggests a list of regions/markets in which the firm has a chance of success. The latter looks for specific opportunities in those regions, engages with their clients and participates in the preparation of proposals/offers. Mapna has also been successful in shaping channels in its targeted markets. In some cases, the firm has even established a local office or a local joint company for those purposes.

The restructuring, however, has merely changed the allocation of responsibilities in the proposal preparation process. The Sales Department in the holding coordinates the process for power plant bids. 20 personnel in the Engineering Department of the EMAN division cooperate with dedicated resources in the Sales Department for preparing technical proposals for bids.

Before 2004, Mapna primarily relied on Ansaldo Energia for understanding clients' requirements and translating them into core equipment block and core equipment specifications. The firm, however, gradually built up its own engineering capabilities for a meaningful engagement with clients. NIAM enabled Mapna to offer standard technical proposals (with possible minor customisations in each project), leading to the preparation of standard price offers. Despite limiting the technological options, the lower costs and shorter completion times of these offers are appealing for some clients.

Non-technical considerations nonetheless can affect the results of overseas bids. For instance, institutes that finance these high-cost projects can also greatly affect the results of the competition. International banks often finance a project on the condition that a certain share of the required equipment or services is bought from the home country of the bank.[35] From another perspective, some firms occasionally offer low prices to win a particular project with very low margins for strategic purposes. As such, the evidence on success and failure in bids does not accurately reflect the accumulation of pre-project capabilities. The above discussion also indicates that the capability to formulate winning bids depends to a large extent on progress in other areas of LSIC.

Winning a number of competitions in regional markets and receiving high technical scores in others suggest that strong pre-bid and bid capabilities have been built in Mapna. Building a bottom-up approach to estimations and a wide integration of project teams in the bid preparation process have resulted in fewer instances of large deviations between bid prices and actual project costs. The Head of the Planning Department in the EPC division says:

> “Many aspects of projects are clear to us now. For instance we have all sorts of templates and project plans for preparing a proposal for a combined cycle plant. We just need to know the objectives of our client and then a project plan is produced at the other end.”

Recent progress in the Strategic Marketing Unit has led to a better performance in bids. For instance, Mapna pulled out of a bid at the last minute before submitting its proposal to avoid a failure due to a new development in the strategy of a competing firm. Vertical integration across the value chain and the development of NIAM have also strengthened the position of Mapna in the local market amidst trade embargos on Iran. Recent investments in Mapna’s project management capability to move towards international norms are promising to expand market possibilities in the future.

Nevertheless, Mapna is still manufacturing under a Siemens license and buys some components directly from Siemens, suggesting a pessimistic alternative reason behind the success of Mapna in some regional markets. Furthermore, latecomer functional SI and

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[35] As such, systems integrators from countries with strong financial institutions have higher chances of winning international projects.

latecomer project SI capabilities in Mapna are primarily built around a specific technology of gas turbine, namely Siemens's V94.2 gas turbines. There is no guarantee that the firm would perform competitively if clients asked for newer technologies or even different components. The Head of Mapna's Sales Unit recounts a case:

> "In terms of performance of the delivered plant we have no significant differences with Siemens in this technology, but some specific technologies may impact on our position. For instance, we are weak in meeting high environmental standards for gasoline burning. We can change the current burners to meet the requirements but our prices will increase because we do not have secure access to this technology."

Post-project

In the case of Mapna, post-project feedback can be studied from two perspectives: the integration of power plant projects and the engineering/manufacturing of core equipment.

Every power plant project has a trial-run period during which Mapna engineers gather information on problems and send them back to the Engineering and Manufacturing Units. Specifically, Monenco Iran in Mapna has a team on every project site to record incidents and send them back to the Central Engineering team, where the data is analysed and engineering procedures are modified accordingly.

Likewise, defects of delivered systems are analysed by teams of manufacturing firms in Mapna where some complex problems are documented and sent back to Siemens for further analyses. However, temporary solutions are sometimes implemented on site to avoid delays in the project. The Head of Engineering Department in Mapna recounts a case:

> "For instance, [commissioning engineers] in a number of projects have complained that the temperature of the left side and right side of combustion chambers are different. This is a problem that needs to be solved systematically in TUGA. But on the project sites, they sometimes devise a short-term solution ... this is like a painkiller."

Mapna receives sporadic feedback from its clients concerning the operation of plants. A new division was established to provide operation and maintenance services (abbreviated to O&M) after the restructuring of Mapna in 2006. This division has attracted professionals with long experience in power plant operation, including the Head of the Operation Department in

Tavanir which is still the largest owner of power plants in Iran. This division also operates the four power plants owned by Mapna.

One particular role of this division is to lead a team of experts from across Mapna to visit the delivered plants regularly. The team aims to listen to operators and get feedback on the quality of project tasks. These data are then analysed by the team to identify improvement opportunities. For instance, recently a suggestion was made by this team to change the composition of expertise in plant engineering teams. If necessary, suggestions from this team are sent to a high-ranking committee in Mapna for further action. The CEO of the group has also forced the team that revises NIAM to bring in some members from the O&M division for the systematic integration of operational knowledge in new versions of NIAM.

The evidence indicates the implementation of some minor modifications in components manufactured by Mapna as a result of this feedback. Engineers and managers who were interviewed in the EMAN and O&M divisions, however, could not recall any major or significant improvements. The manufacturing firms had not yet developed mechanisms to process this feedback systematically. Engineering departments in these firms have been overwhelmed with project tasks, such as generating documents and resolving on-site incidents, and have thus been left with almost no resources to develop analysis capabilities. As the evidence shows, investment in the analysis capabilities was not previously among the priorities of senior management. Mapna has, however, recently started analysing the behaviour of turbines.

Analysis and interpretation

The initial strategy of Mapna was to focus on project management and to buy in the equipment and engineering services for projects. Inspired primarily by the attitudes of the CEO, the firm acquired knowledge of organising and managing projects from a well-known international project management company. Mapna improved upon this capability through learning by doing in consequent projects, using a mix of centralised and decentralised project control systems, and learning some elements from Ansaldo Energia under technology transfer agreements. A firm-specific capability for project management was therefore gradually developed which was benchmarked with Siemens at later stages.

Facing a rapidly growing demand in the local electricity market, Mapna changed its strategy to enter into plant engineering, manufacturing core equipment and erection/installation tasks in projects. Although the major aim was to reduce risks in projects, this vertical integration was also economically attractive. Building on progress in its latecomer functional SI capabilities, Mapna developed a standard plant design (NIAM) to minimise the engineering activities of projects and transform manufacturing of core equipment to a mass manufacturing style. NIAM enabled the firm to achieve internationally competitive levels in project completion times, to meet the rapid growth of local demand and even finish some projects earlier than the contractual obligations.

In response to the decline in public investments in new plants in Iran and the rise of local competitors, Mapna diversified into other project markets to ensure its growth. More sophisticated demands of new clients in overseas markets and the local market for other energy projects, coupled with the ambitions of the senior management team motivated a transition from local practices of project management towards international ones. Dedicated organisational resources in the new structure and the commitment of senior management to establishing challenging internal goals[36] for projects were essential to progress in this transition. The challenging internal goals encourage continuous improvements across Mapna and create grounds for discussing inter-departmental conflicts during projects.

As Figure 7-6 shows, the firm has accumulated basic and intermediate levels of project SI capability. Early progress in project management capability was enabled by a protected growing local market. The capabilities were built by learning from international firms and the force of an internal commitment to improvement at that stage. The firm-level initiatives (compared to those affecting a single project), such as the development of NIAM, vertical integration in manufacturing and transformation to a holding structure, were very significant at the second level of capabilities. The rise of competition in the local electricity market and more sophisticated demands of clients in new markets encouraged a transition towards more internationally acceptable practices.

[36] These goals are defined to encourage achieving the best class norms in projects.

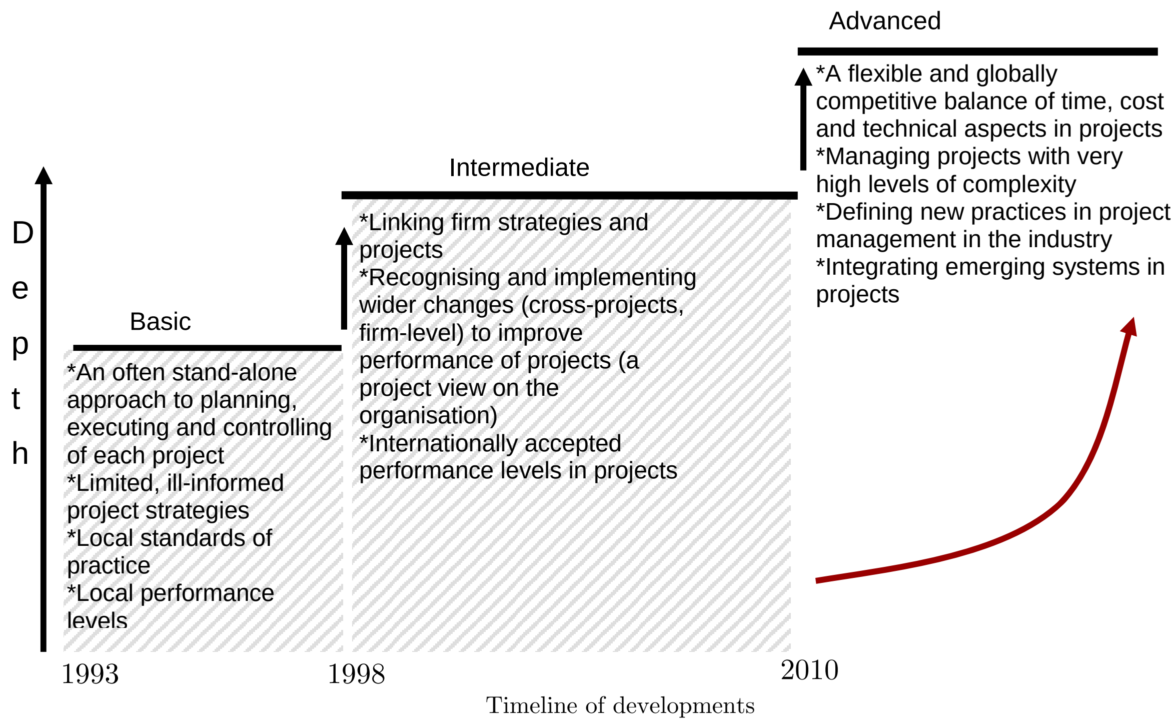

Figure 7-6: the evolution of latecomer project SI capability in Mapna: project part.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

Figure 7-7 shows that Mapna has moved upwards from the basic level in pre-project capability but has not yet perfected the intermediate level. Although rough estimation activities existed to secure early projects, participation in serious competitions outside the local electricity market in later stages induced the development of attributes for a bottom-up, more accurate approach to estimation. These elements were enhanced over time but the comfort of a protected growing local market did not encourage Mapna to develop them seriously. The rise of competition in the local market and new market strategies within the firm led to further development of bid capabilities through establishing dedicated departments, preparing a formal process for bid preparation and allocating resources for marketing and gathering market intelligence. Gathering information on the practices and structures of Ansaldo and Siemens was significant in building these attributes. Although the development of latecomer functional SI and project SI capabilities has created certain market opportunities, the overall systems integration capabilities of Mapna have advanced around a certain technology of power plants and a certain approach to minimising engineering activities in projects, both of which may create serious limitations in other competitive markets.

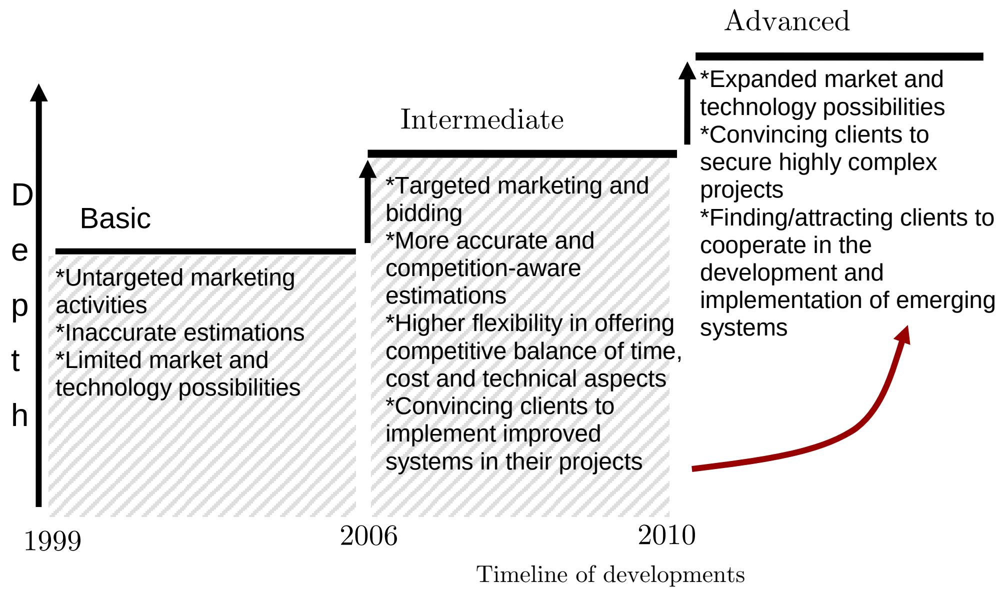

Figure 7-7: the evolution of latecomer project SI capability in Mapna: pre-project part.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

Figure 7-8 shows that Mapna has started to build the intermediate level of post-project capability but has not yet completed the journey. A separate division was created for operation and maintenance services in 2009 and is currently operating four power plants owned by Mapna. The evidence shows that feedback was entered into engineering and project management through the presence of an engineering office at project sites and the integration of operational experience in revisions of NIAM. Although regular visits to the delivered plants have generated some feedback, they were not effectively used due to the lack of clear organisational arrangements in the Manufacturing Division of Mapna. More importantly, the weakness of functional SI capabilities did not allow for full technical analysis and conceiving modifications in some cases.

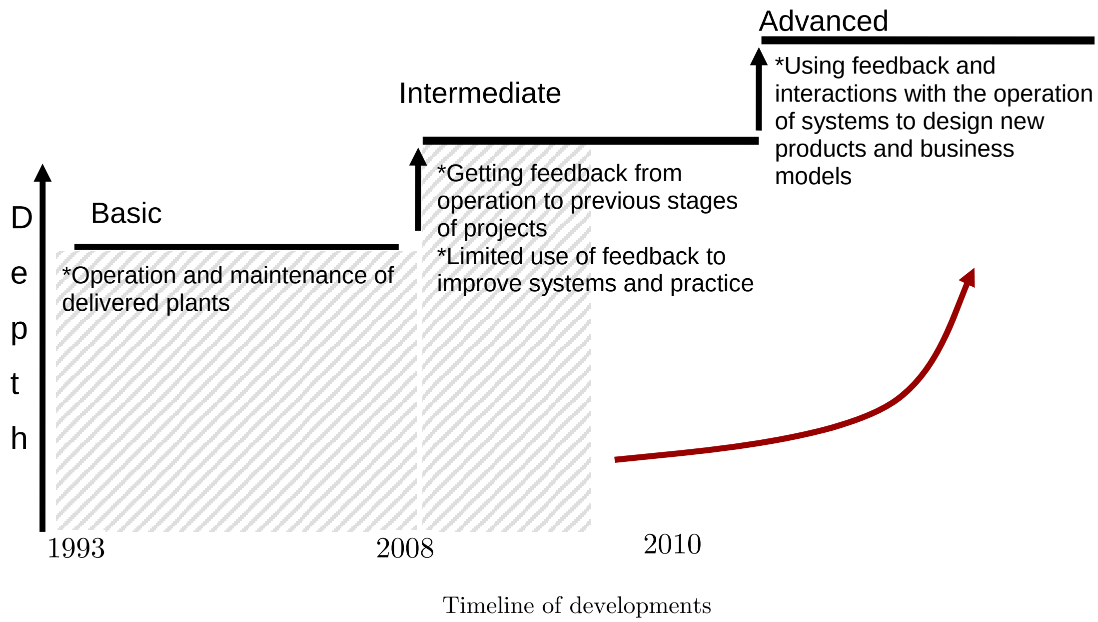

Figure 7-8: the evolution of latecomer project SI capability in Mapna: post-project part.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

7.5.3 Strategic SI capabilities

Mapna was established by Iran's Ministry of Energy as a project management company for local thermal power plant projects. The aim was to cut the costs of projects by replacing expensive international systems integrators and promoting the share of local content in projects. The name of company clearly reflects the intentions. Mapna is an abbreviation of Iran's Power Plant Projects Management Company in the Persian language. However, the firm moved vertically along the value chain to build wider engineering and manufacturing capabilities in later stages.

Mr.Marjuvi, the first CEO of Mapna, was a key figure in shaping the initial path of LSIC evolution in the firm. Mr.Hajirasoliha, the long time CEO of Farab and a former colleague of Mr.Marjuvi in the Ministry of Energy, describes his attitudes:

> "Unlike us, he believed that [Mapna] should not waste time reinventing the wheel. He signed a contract with Monenco Agra Canada to tell them what to do, how to organise Mapna and how to manage power plant projects."

Mr.Marjuvi promoted the idea of prime contracting, focusing on the project management of complex projects and outsourcing technical tasks. The second CEO of Mapna was a visionary. As was discussed in previous sections, he was insistent on enhancing the engineering capabilities of Mapna and justified the costs and risks of trial-and-error learning in power plant engineering to the Board. While NIAM was under revision, he forced the team to integrate operational and maintenance views in the new versions of NIAM. Vertical integration into manufacturing, engineering and construction businesses, transforming manufacturing of core equipment to a mass production mode and restructuring the firm into a holding company were other changes that were strongly pushed by him. A member of Roland Berger team, the consultant of Mapna's restructuring in 2006, says:

> "He had a vision of how the firm should look. I think we were hired to convince other members of the senior management team that this was a suitable option."

In the late 1990s, the prospect of new thermal power plant projects in the local market was huge for Mapna, equal to 2 billion dollars' worth of new projects every year at the time. The main objective of the senior management team in Mapna was to secure access to the required equipment and services to respond to this growth and capture more added value from projects.

A major strategic decision was to integrate vertically along the value chain and enter into engineering, manufacturing and erection activities.[37] To implement this decision, Mapna acquired a local engineering company and a firm working in the erection and construction of plants, and established new firms for manufacturing core equipment. These integrations were discussed in more detail in the introduction to this chapter. The strategy of manufacturing core equipment later proved successful in enabling the firm to develop NIAM and meet the local demand in the face of new trade embargos. The integration also expanded the market possibilities of the firm so that Mapna currently participates in competitions for whole projects and can also join its local competitors to merely provide them with engineering and the supply of core equipment. Mapna has also invested in its own power plants and is currently the biggest private owner of plants in Iran. This integration has not only diversified income sources but has also created demand for its EPC and manufacturing firms.

In its first 12 years of existence, Mapna enjoyed a protected growing market in the local electricity sector. Organising the response to this demand was so overwhelming that the firm

[37] The prospects of large orders from the local client justified these investments from an economic perspective.

was unable to adopt a more strategic view on other aspects of LSIC development. A previous strategy consultant to Mapna says:

> “Senior managers had a good strategic understanding but they were very busy with projects; some of them even had to travel around the country and abroad to find suppliers. They could not allocate time for strategic discussions.”

The Ministry of Energy opened up the market for private investors in 2004 and started promoting competition from other local contractors. Analysis by Mapna’s Strategic Planning Office showed that new investors had preferred to buy systems integration services from leading firms in the first three years following 2004. In addition, Mapna had grown over time by acquiring existing local firms or investing in new firms, making the management of the firm increasingly complex.

Even though Mapna has made strategic moves throughout its history, the first formal exercise for strategic planning dates back to 1998, six years after its establishment. This attempt, however, did not produce concrete outputs for implementation. Under pressures from the Board, a formal strategic plan was produced in 2003 which has been revised annually since then. The mounting complexities of internal and external developments drew more serious attention to strategic analyses in 2004.

An outcome of the new conditions was the definition of specific organisational roles and processes for the continuous revision of strategies, and the deployment of tools for the operationalisation of plans. The number of staff in the Strategic Planning Department increased to four full-time analysts, and a new unit was established for regular monitoring of the implementation of plans. Mapna currently uses a formal strategic planning approach and strategic management tools, breaking down long-term objectives into medium- and short-term plans for its departments and divisions. The objectives are revised every six months. Some continuous improvement activities are undertaken in the firm through committing to the ISO Quality Management System and EFQM assessments.

Due to the heavy load of project-related tasks in Mapna’s divisions, enforcing formal future-oriented initiatives by the Strategic Planning Department has occasionally resulted in conflicts across Mapna. The Head of the Strategic Planning Department says:

> “There were some arguments in the Strategic Issues Committee. Senior managers of some divisions complained that they were not happy with us pushing for

> regular preparation of objectives and plans. The CEO clearly said that they [the Strategic Planning Department] were doing his job. He should follow the long-term objectives but he had delegated it to them ... the disputes were eventually resolved."

The new vision of Mapna was to transform the firm into a reputable international contractor in the field of industrial and energy projects. The emphasis was on penetrating overseas markets and acting as a provider of engineering services and core equipment for projects. The scope of business was also refined to enter into operation, maintenance and after-sales services of power plants. To implement these new strategies, Mapna hired Roland Berger, a German consultancy, to carry out a restructuring project officially titled 'Restructuring Mapna Group: Preparation for Growth'. The project took over a year, through which several options were discussed with the senior management team and some international firms were benchmarked to gain insights. In the end, a multi-divisional structure was adopted. A particular output of this project was to establish R&D departments across Mapna primarily for improving the products and services of the firm, thereby strengthening its market position. The Head of Strategic Planning Department says:

> "We cannot buy technology forever. Our vision is clear. We aim to become number one in our region for power plant projects. We cannot achieve this by relying on others to see what they produce and manufacturing an older version of that here. It [our vision] requires a big leap, we need to advance our knowledge ... Our competitive situation has changed. If we do not start developing technological knowledge now there is no guarantee that we can enjoy the same market position in four years ... We should offer new technical specifications on the market."

Although a portion of project tasks are still performed in headquarters within the new structure, Mapna headquarters now focuses on business development, financing, strategic marketing and promoting improvement activities across the divisions. The new division of labour in Mapna has also created some organisational resources for the enhancement of capabilities. Organisational arrangements have been established for sensing and discussing the developments in markets and technologies. A department has also been created for gathering market intelligence and information on competitors. Meanwhile, the Sales Department and the newly-established O&M division engage with clients to get a sense of evolving needs. As for technological changes, the EMAN division has become responsible for monitoring the global evolution of power plant technologies and suggesting new technological strategies.

In addition to these sensing mechanisms, a number of committees have been organised across Mapna for discussing strategic matters. The history of some committees goes back to 2003 when Mapna obtained its ISO Quality Management certificate and was subsequently assessed against the EFQM model. The committees were extended and gained more importance as a result of further attention to strategic planning in 2004. Issues related to new businesses, new markets, partnerships, acquisitions and other strategic aspects are discussed in a very high-ranking committee called the Strategic Issues Committee.

Several instances of strategic changes have been discussed in this chapter, including the start of R&D activities, entering into the O&M market, diversifying into other project markets and restructuring Mapna, all of which have permitted further development of LSIC. However, further development of functional systems integration capabilities was neglected in the early stages of the growth at the expense of building other capabilities for managing a large number of projects that were given to the firm on an offer basis. Although several cases of top-down strategic mechanisms in Mapna have been illustrated throughout this thesis, effective bottom-up channels for sharing and discussing strategic matters have not yet formed. A former strategy consultant who was engaged with the firm for over a year talks about his experience:

> "Some people in the Strategic Planning Department could not accurately comprehend the essence of the competitive advantages of ABB and Siemens, but people in the Procurement Department knew it better. This type of knowledge was not reflected in the strategies. There are many good information islands in Mapna but they are not transferred to a higher level for building strategic inputs."

Analysis and interpretation

As Figure 7-9 illustrates, Mapna has moved towards building the intermediate level of strategic SI capabilities but has not yet completed the journey. Although the firm has implemented several strategic changes in the past, the rise of competition in the local electricity market and the liberation from the pressures of organising a large number of projects in the early days paved the way for the implementation of a formal approach to strategic planning and control. Mapna's CEO is committed to supporting strategic analyses and planning. Even though top-down initiatives in strategy and a formal mechanism for strategic planning exist, organisation-wide bottom-up channels for sensing and discussing strategic issues have not been developed.

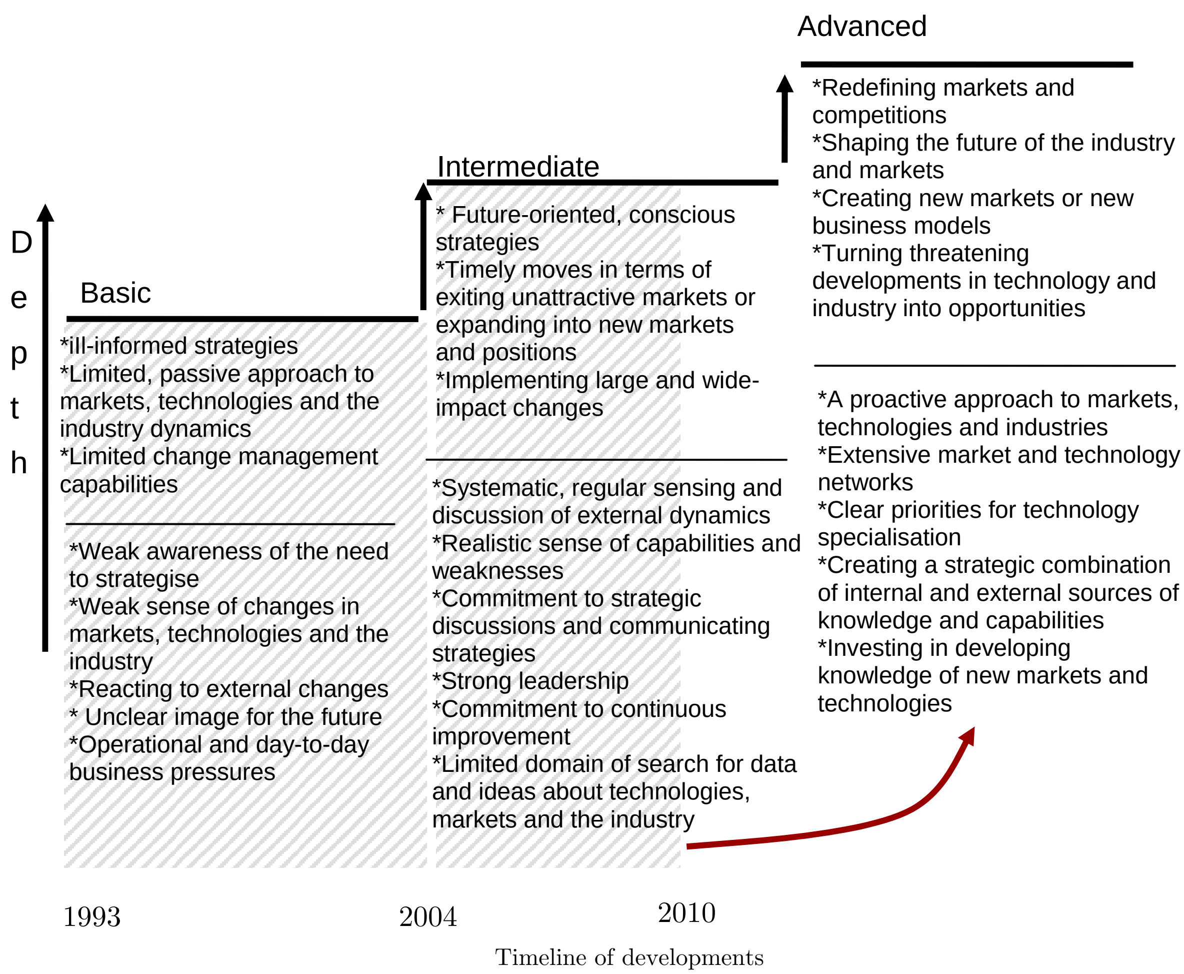

Figure 7-9: the evolution of latecomer strategic SI capability in Mapna.

Note: The shaded area shows the progress to date and the approximate time of achieving each level of depth in this capability, and the curved arrow indicates a possible direction of the future journey.

7.6 Summary

This chapter presents evidence of developments of micro-level attributes including people, knowledge, processes and structures underlying each capability to investigate evolution across the three core constituent parts of LSIC. The investigation is carried out within the wider context of the firm and its external environment to reveal a picture of the dynamics behind capability evolution.

Mapna was established to manage thermal power plant projects in Iran's electricity sector, but gradually entered into overseas markets for similar projects and diversified into local markets for other complex projects. As the evidence shows, the firm has progressed unevenly in the accumulation of LSIC so that currently it has significantly progressed in building intermediate levels of project SI and strategic SI capabilities according to our framework, but has only recently completed assembling the basic innovative level of functional SI capabilities. This journey towards higher levels of LSIC was not fully planned from the outset but, instead, evolved over time in response to the dynamics of the external environment and in line with internal aspirations.

The evidence shows that the three core constituent parts of latecomer SI capability have fed into each other and co-evolved during Mapna's journey. For instance, formulating better bids and offers depended in part on functional and project SI capabilities to understand client's needs and formulate proper estimations. Similarly, progress of the latter capabilities depended on the former to secure new projects, the lifeblood of a project business.

The growing local market was a substantial factor in the evolution of the three core constituent parts of LSIC. The growing and protected market of the local electricity sector supported the initial growth of Mapna's capabilities and justified the vertical integrations along the value chain. However, the comfort of the protected market sometimes militated against further growth of particular capabilities such as pre-project and more complex attributes of functional SI. The firm even relied on foreign systems integrators to fully understand the technological needs of its clients until 2004, 12 years after its establishment. Mapna also started to develop formal structures and processes for pre-project activities from 2004 and to develop the attributes underlying the technological understanding of core equipment in a power plant from 2007. Overwhelmed with organising a growing number of projects during the first 15 years of its life (1993-2007), Mapna could not reflect on the implications of sustainable growth of LSIC.

However, participating in competitions in other project markets, locally and internationally, balanced the above negative impacts, initiating the progressive build up of higher levels of project SI capabilities and functional SI capabilities. The emergence of competitive threats in the previously protected local market also intensified the forces behind the accumulation of higher levels of LSIC, in particular functional SI capabilities and strategic SI capabilities.

Although the expansion of market possibilities depended largely on advances in LSIC capabilities, the desire to sustain and enhance the market position also affected the evolution of capabilities. Recent investments in basic innovative and intermediate innovative functional capabilities were made with the hope of opening up new market opportunities in the operation of power plants and other energy projects. Similarly, the desire to enhance Mapna's position in the local electricity market incentivised technological activities for improving the existing turbine during which higher-level attributes for functional SI capabilities may potentially be assembled. Similarly, Mapna Standard Design for Gas Power Plants (NIAM) was developed to sustain the position in the local electricity market.

The evidence reveals the significance of intelligent and demanding clients in the evolution of capabilities. The policy of the state client in the local electricity market for dividing aggregate demand of a long period into packages of projects enabled the firm to negotiate knowledge transfer contracts. The same client also supported the development of NIAM, leading to the growth of some capabilities and the downgrading of others. NIAM enabled Mapna to reach internationally competitive norms in project completion times but slowed down its progress in developing other attributes of functional and project SI capabilities which permit customisation in each project. Its weak customisation capabilities may damage the firm's position in serious competitions. By contrast, comparatively more sophisticated requirements of new clients, in local and overseas markets, have stimulated the accumulation of higher-level attributes in functional and project SI capabilities.

The strategy of Mapna has been critical in shaping the course of capability evolution. The initial intention of the firm to be a pure prime contractor resulted in a systematic learning of project SI capabilities and was a reason behind the late, trial-and-error based approach to the enhancement of functional SI capabilities. However, the subsequent vertical integration into the manufacturing of core equipment and transforming the production mode to mass manufacturing enabled the firm to decrease the duration of projects, which simultaneously, over time, degraded the attributes of functional and SI capabilities for delivering fully-engineered plants. Likewise, forward integration into financing power plants allowed for a trial-and-error approach in building the operative level of functional SI capabilities, as the clients would not allow the firm to experiment in their plants. The recent move into the operation and maintenance of plants promises to provide feedback for further developments in capabilities.

Leadership has played a significant role in the observed evolutionary paths. It has stimulated and even pushed the accumulation of higher-level attributes for functional, project and strategic SI capabilities through setting challenging goals, enforcing formal planning arrangements and envisaging transformations in the organisation. The leadership of Mapna has also justified the costs of trial-and-error learning as required for progressing in certain levels of LSIC. However, unawareness of the long-term, competitive implications of technological dependence on leading firms for engineering and troubleshooting of core equipment was significant in suspending investments in understanding the behaviour of core equipment until early 2008, 16 years after the firm was established. The impossibility, due to various reasons, of continuing to use Siemens's expertise to resolve emerging behaviours in the delivered turbines has seriously threatened the firm's image in recent years. These incidents have forced senior managers of the firm to revisit their assumptions about outsourcing certain technological activities.

Learning from suppliers and sub-contractors (sometimes competitors in other projects), whether leading suppliers such as Siemens or smaller specialised suppliers, has been substantial in accumulating attributes across the three core constituent parts of LSIC. This learning has appeared in several forms such as borrowing ideas, building attributes through formal transfer agreements or as by-products of such formal activities. Particularly in this case study, formal knowledge transfer agreements were permitted by a growing local market and the client's policy of dividing the aggregate demand of a period into packages of projects.

In particular, making deliberate changes to the organisational structure has been shown to affect the evolution of LSIC. A mix of centralised and decentralised approaches to project planning and control has allowed for continuous improvements in project SI capability. In another instance, the division of labour within the new structure of Mapna has accelerated the growth of LSIC by creating organisational resources to concentrate on improving some capabilities.

However, the evidence indicates that the mere existence of a formal structure or mechanism does not guarantee progress in capabilities as other attributes are also required. Although formal procedures existed in Mapna for gathering and reflecting on feedback for manufacturing core equipment, the post-project capability has not advanced due to the lack of analysis and modelling attributes (a part of basic innovative functional SI capability) in the firm and, more importantly, due to an absence of 'will' in the manufacturing divisions of Mapna to build capabilities to act on the feedback. From a wider perspective, however, the establishment of certain departments reflects the emergence of some capabilities or, equally importantly, can indicate the level of commitment for advancing those capabilities.

The technological characteristics of the product have also affected the journey. The technological possibility of replicating similar designs of core equipment blocks across all gas-fired plants, which was welcomed by the local client, facilitated progress in certain capabilities. However, at the same time, this practice concealed weaknesses in other aspects of project SI and functional SI capabilities which, in turn, disincentivised the accumulation of corresponding attributes. Interestingly, the necessity of customisation for each project site in combined cycle plants, a different technological domain, was the first indicator to alert the firm to some shortcomings in its capabilities.

Overall, the evidence reveals that the existence of a ‘will’ and the strategic capability were necessary for progressing in LSIC accumulation. This ‘will’ can be motivated or created by a range of internal and external factors such as clients’ requirements, competitive forces, unexpected developments in the external environment, aspirations inside the firm, the emergence of complexities in the management of the firm and seeking higher profits. For instance, accumulation of the operative level of functional SI capabilities eventually occurred, despite internal opposition and technical challenges, when the CEO realised it was necessary for the growth of the firm and pushed it forward. A closely-related factor influencing the evolution has been self-confidence. In this case, a lack of self-confidence, and an over-reliance on licensors, has been a major barrier, slowing down the potential build-up of basic innovative and intermediate innovative attributes in functional SI capabilities. However, countervailing factors such as the threat of competition in the local electricity market, the necessity of dealing with unexpected behaviours through the lifecycle of plants and the internal aspirations of the firm to gain competitive advantages in the local electricity market have led to recent investments in basic innovative and intermediate innovative levels of functional SI capabilities. Mapna has recently successfully put in use its existing gas turbines in a new application setting and has resolved some cases of emerging problems in the delivered turbines independently from leading systems integrators. Nevertheless, the initiative to modify the existing gas turbine to improve its performance and the initiative to design a medium-sized gas turbine were at the early stages of progress when the fieldwork was completed in early 2010.

Mapna made strong progress in catching up against the three core constituent parts of LSIC. In less than 20 years, LSIC evolved from small beginnings to a significant stage, underpinning national and regional successes in gas-fired and combined cycle power plant projects. Despite the remarkable overall achievements in a short period of time, the firm could have started earlier to deepen its functional SI capabilities. Furthermore, its LSIC in the power plant industry has only developed around V94.2 gas turbine technology. Based on the firm’s project references, it has been impossible to empirically investigate its systems integration performance for other technologies. However, as far as the evidence suggests, the firm would have to improve on its functional SI capabilities, although not very significantly, to achieve the same level of performance in other technologies.

The next chapter attempts to unravel the patterns, including the similarities and differences, which emerge from cross-case analysis in order to deepen our understanding of the evolution of LSIC.

8. Chapter Eight: Cross case analysis

The two previous empirical chapters presented the evidence and findings on the origin, composition and evolution of LSIC in each of the two case studies of this research. Evidence was gathered on the development of micro-level attributes including people, knowledge, processes and structures underlying each LSI capability and on the wider context of the firm and its external environment. Each chapter revealed how the three core constituent parts of LSIC co-evolved and fed into each other through a path that was shaped by the interaction of external forces with internal factors. This chapter embarks upon a cross-case analysis to enrich our understandings of LSIC evolution.

In the analyses of this chapter, we juxtapose the evidence and findings of one case with the other in terms of the framework we have adopted for the empirical investigation of capabilities. This analysis hopes to reveal new insights into the composition of LSIC, the rates and directions of its evolution, including commonalities and differences between the two cases and explanations for these patterns. For instance, it emerges that Mapna was comparatively late in initiating the accumulation of operative and basic innovative levels of functional SI capability, leading to restrictions on the success of the firm in competitive markets and drawbacks to providing technical services throughout the lifecycle of its plants. This chain of comparative inquiry hopes to illustrate new aspects of LSIC evolution, and we attempt to organise the evidence to build a conceptual framework of variables, describing how the evolutionary paths were specifically shaped in each firm of our study.

The chapter shows that LSIC evolved from small beginnings in project management in a protected local market into significant stages in all the three core constituent parts of LSIC, underpinning the expansion of market possibilities and success in competitive national and overseas markets. In attempting to compare the two cases, we identify major differences in paths and patterns of change in the two firms, within the general context of rapid progress. As this chapter shows, there were imbalances, spurts of rapid capability growth, periods of falling behind in specific areas, close connections and relationships (amounting to a co-evolution of capabilities) and major investments and strategies to remedy imbalances in order to sustain the firms' progress. In our review of the theory and literature relating to capability evolution (see Chapter Three) we found no existing research or conceptualisation to help us understand and interpret these highly complex patterns of firm-specific capability evolution. However, in a wider search of the innovation literature in the context of large technical systems, we see that one author in particular, namely Thomas Hughes, has dealt with similar complex patterns in describing the commonalities and differences observed in the expansion of electricity networks in industrial nations. Therefore, in order to help us interpret our findings, we will briefly introduce at this stage the key concepts and definitions of Hughes's approach in section 1 of this chapter, and will return to this in the conclusion, to explain how Hughes's analysis of reverse salients and critical problems (Hughes, 1983) can be extended to our case material.

The chapter is organised into four sections. It starts with a brief review of Hughes's approach in analysing the evolution of large technical systems. The second section is an in-depth, cross-case analysis of each major constituent part of LSI capabilities. It highlights the emerging patterns and discusses some possible explanations. The third section presents the cross-case analysis across the levels of the three core constituent parts of LSIC. The discussions and findings in this section are organised under the themes of similarities and common patterns, differences in the progress of LSIC, and the dynamics behind LSIC evolution at the firm level. The final section summarises the findings of this chapter and presents a conceptual framework to help identify and show links between the important variables that have shaped the firm-specific paths.

8.1 An introduction to Thomas Hughes's approach in analysing the evolution of large technical systems

Hughes (1983) investigates the changes in the configuration of electrical power systems during the half-century between 1880 and 1930. In particular, he explains how the small lighting systems of the 1880s evolved into the large regional power systems[1] of the 1920s over the period that covered World War I, with lasting effects on the systems' evolution. The study focuses on three industrialised nations, namely the USA, the UK and Germany.

Hughes approaches the subject from a systems perspective and considers electrical power networks as large technical systems embodying the physical, intellectual and symbolic resources of the society that constructs them. He organises the evidence into five phases of system evolution: (1) invention and development of the system; (2) technology transfer between societies; (3) system growth; (4) substantial momentum in growth; and (5) evolving regional systems with distinctive styles. The analysis shows that each phase has its own

[1]Although Hughes originally used the term 'technological system' in his study of networks of electrical power, he then changed the term to 'large technological systems' (Bijker et al., 1987). The term 'large technical systems' was then used in a later book co-edited by Hughes (Mayntz and Hughes 1988). Other scholars, however, have used both terms to apply Hughes's concepts to such systems (for example, see Davies 1996; Jacobsson and Bergek 2004; Nithingale et al., 2003; Summerton 1994).

dominant characteristics and system builders,[2] professionals who preside over the system, have particular capabilities and interests during each phase. However, one aspect of his work is of particular relevance to the current research: the evolution of three regional systems in Hughes's study features a set of similarities and specific differences. In attempting to explain these complex patterns, Hughes develops an integrative framework containing internal dynamics of technology and contextual, 'cultural' forces. The following paragraphs present his framework very briefly.

In his study of the system growth from the third phase onwards, Hughes deploys the concepts of reverse salients and critical problems to explain the complex, unpredicted internal dynamics of technological evolution. The concept of reverse salients is borrowed from historical research in the military. Reverse salients are those sections of an advancing line, or front, that have fallen back. Hughes applies the same concept to an expanding technological system:

> "The idea of a reverse salient suggests the need for *concentrated action* (invention and development) if expansion is to proceed. Reverse salience *appears in an expanding system* when a component of the system does not march along harmoniously with other components. As the system evolves towards a goal, some components fall behind or out of line. As a result of reverse salients, growth of the entire enterprise is hampered or thwarted and thus *remedial action is required.* The reverse salient usually appears as a result of *accidents and confluences* that persons presiding over or managing the system do not foresee, or, if they do foresee them, are unable to counter expeditiously. The causes of the lag can arise from within the system, from its environment, or context; or from some complex combination thereof. The reverse salient will not be seen, however, unless inventors, engineers, and others view the technology as a *goal-seeking system.*" (Hughes 1983, p79-80; portions of text are converted to *italics* for emphasis).

He argues that (probably most) inventions and technological developments in electrical power systems emerged from efforts to correct reverse salients. System builders saw reverse salients as impediments to the progress of the system towards its goals and so desired to remove them. As such, they defined the reverse salient as a problem or a set of problems that, when solved, would bring the system back into progress. However, the solution to the problem for one component often caused imbalances somewhere else in the system, and these were then treated as new problems.[3] The continuous emergence of reverse salients and the ongoing solution of critical problems inherent in them by inventors, engineers and entrepreneurs

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[2] He often refers to inventors, engineers and entrepreneurs as system builders.
[3] Hughes argues that the concept of the reverse salient is preferable to disequilibrium or bottlenecks because it better reflects the complexities, while disequilibrium suggests an abstraction of physical science and a bottleneck is geometrically too symmetrical (p79). However, in later chapters, he uses 'reverse salient', 'imbalance' and 'bottleneck' interchangeably (for instance see pp371-372).

provided an internal driver and an increasing momentum for the systems. However, this momentum could be disrupted by strong enough (internal or external) forces (p285).

But how are reverse salients identified and defined? Analysis of a growing system often revealed its inefficient or backward components, reverse salients:

> "They [system builders] approached the challenge [of correcting the reverse salient] by defining the reverse salient as a set of "critical problems"... Outstanding inventors, engineers, and entrepreneurs usually have a record of defining and solving such problems ... As observed in the case of Edison, a person conceptualizing a technology [a large technical system] systematically or holistically often recognized inadequacies in the patterns formed by the system's components and networks. Those who did not observe system growth firsthand surveyed the publications of others who did." (p80) "In fact, the inventions were particular solutions to particular critical problems defined within the context of place, time and other circumstances." (p95)

Hughes shows that a qualitative change took place in the nature of the reverse salients as the electricity systems progressed. While in the early phases the reverse salients and critical problems were often technological in nature (for example long-distance transmission was a reverse salient in the further expansion of the direct current electricity system), they were transformed into financial and managerial challenges of a growing large-scale system in later stages. Changes in outside factors also created impediments to expansion. System costs often increased because of changes in the price of inputs or because of regulatory requirements. The effects of these changes were usually internalised in the system through the identification of particular components or connections of the system as critical problems.

Hughes incorporates elements of the cultural context into his discussion to explain the essence of regional diversity. Generally, the regional systems had similar critical technical problems and similar solutions, partially due to the existence of a common international pool of technology. The differences, however, stemmed mostly from the non-technological factors of the cultural context; factors such as geographical, economic, organisational, behavioural, contingent historical and entrepreneurial conditions.

These factors did not operate deterministically to shape the technology; instead they acted through the mediating agency of individuals and groups. For instance, natural geographical features were given conditions in every region; however, engineers selected or invented an appropriate technology to adapt to them. Similarly, although the same economic principles[4] governed the systems, there were various ways in which these principles were applied in each region. As such, the external, cultural factors gave control and direction to the evolution in each region.

As the previous chapters and also the following sections show, firm-specific recurring periods of growth, stagnation or downgrading have been observed in each of the three core constituent parts of LSIC in our study. This process has been shaped by complex interactions of evolving internal and external forces and has ended up with distinct levels of achievement in each firm. Although Hughes's concepts were originally developed in a different context and contrast in some areas with other contributions such as Sahal (1985),[5] his ideas can potentially help us interpret our findings. In particular, his approach has potential merits in (a) explaining both the similarities and differences observed; (b) dealing with extremely complex situations during the system's progress in which accidents as well as trends play a role; and (c) explaining the state of dynamic imbalances in the system resulting from uneven progress within the system and the changing external environment.

Before proceeding to the empirical analysis, it is necessary to elaborate on the kind of system this research deals with. LSI capabilities are considered as a system of interacting constituent parts in the following discussion. Several cases of interaction and interdependency among the three core constituent parts of LSIC are described in this chapter and are restated briefly in the conclusion.[6] Furthermore, similar to Hughes's analysis, the concept of 'system' is used more loosely compared to the system theories literature in the sense that some of the parts in the system are not technical, and the system is not always centrally controlled.

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[4] It includes factors such as load factor, economic mix and pricing on the basis of cost notwithstanding (p465).
[5] Sahal (1985) presents another view of innovation processes in three complex products based on a theory of systems. He proposes that technological evolution is shaped through innovative activities happening on specific innovation avenues. As such, a wide variety of innovations originate from learning to overcome natural limitations arising from the inner logic of technological progresses (the relation between technology size, structure and form). While various innovation avenues might exist to continue from one specific point, it is chance that determines which among them will be chosen. However, Hughes's concepts are more relevant to our research because: (1) Sahal is mainly focused on the inner logic of technological progress and speaks very little about the role of external factors (only very briefly in the third paragraph of p80 and the last paragraph of p81); (2) interestingly, Sahal uses similar concepts such as limitations to progress and momentum but does not cover non-technological limitations to the progress; and (3) Sahal only presents one variable, *chance*, to explain the process of selection among innovation avenues. This appears to be insufficient for understanding the deliberate decisions of firms and the dedication of people to pursuing one path. Overall, Hughes provides a more comprehensive approach regarding our purposes.
[6] One could alternatively start the discussion by defining the latecomer firm as a system instead of LSI capabilities being the system. However, this change in the unit of analysis introduces unnecessary complexities into the discussion and makes it hard to follow while the essence of the arguments remains very similar.

8.2 Cross-case analysis at each level of the three core constituent parts of LSIC

As Figure 8-1 and

Figure 8-2 show, Farab has accumulated the basic innovative and intermediate innovative levels of this capability, and has recently embarked upon building the advanced level, whereas Mapna has recently accumulated the basic innovative level, and has invested simultaneously in the attributes underlying the intermediate level of functional SI capabilities, such as scientific equations and modelling applications.

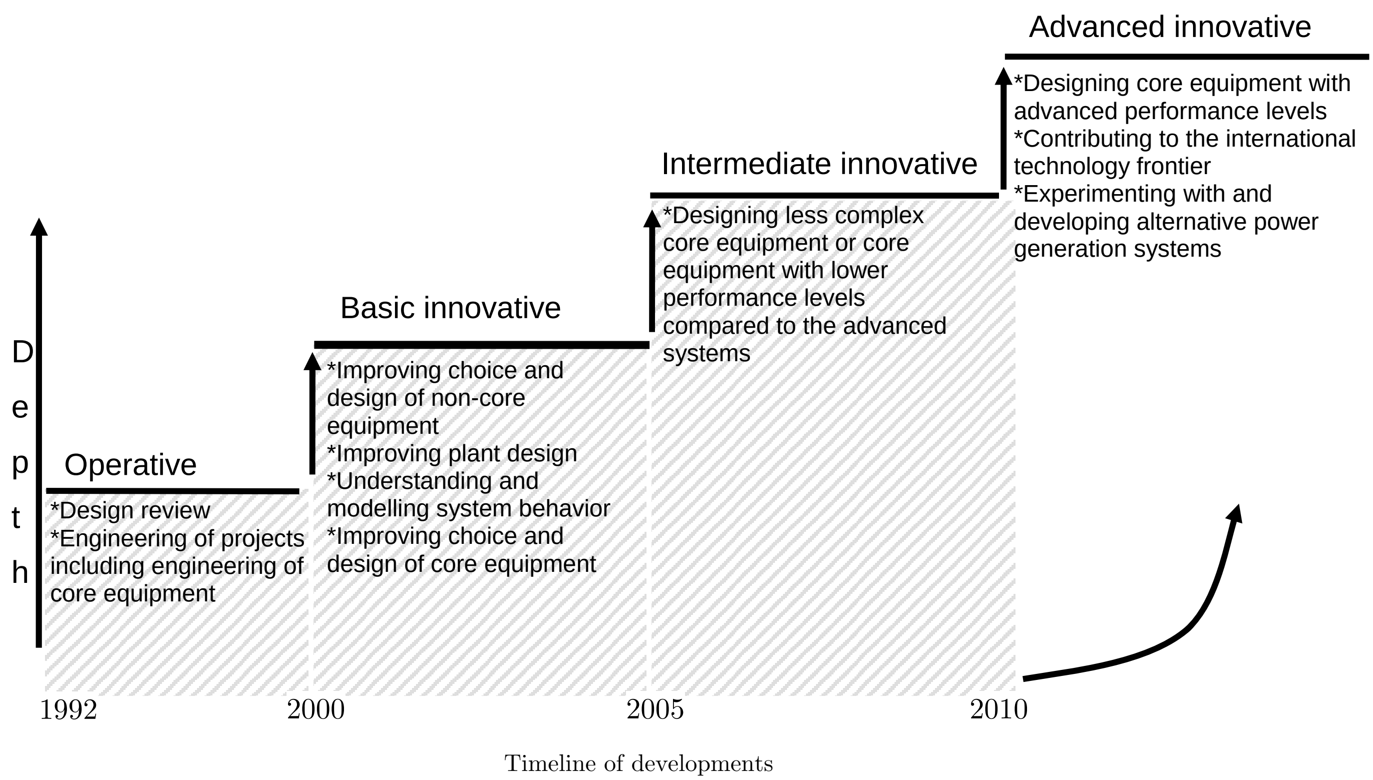

Figure 8-1: the evolution of latecomer functional SI capability in Farab.

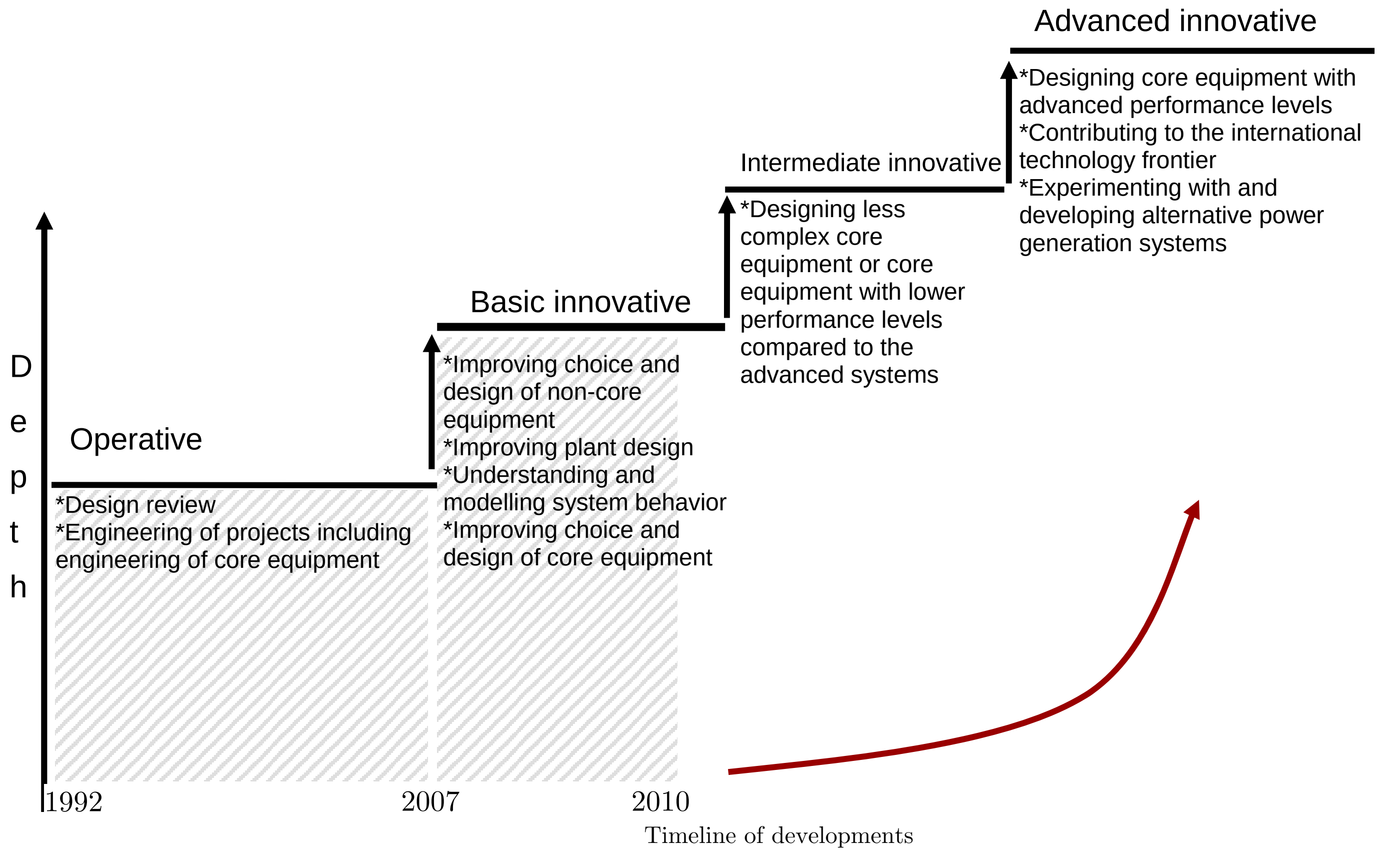

Figure 8-2: the evolution of latecomer functional SI capability in Mapna.

8.2.1 Operative Level of Latecomer Functional SI

In comparing the two firms, we discover that Mapna was comparatively late in accumulating operative functional SI capabilities. The evidence reveals the variety of reasons behind this observation. Firstly, and probably most importantly, deeper functional SI capabilities were not considered as critical parts of the organisational concept at the outset in Mapna; in other words they were not perceived as reverse salients. Mapna focused on learning project management methods from its international consultants, whereas internal discussions in Farab revealed that building functional SI capabilities was the key to successful project management in hydro power plant projects. The perspectives of the senior management teams, in particular the CEOs, affected these decisions, as one was very concerned about building local engineering capabilities while the other was more concerned with the complexity of managing several contractors in a thermal power plant.[7]

Secondly, the technological characteristics of hydro power plants are different from thermal plants, in particular, gas power plants. Hydro turbines have to be designed and engineered

[7] We have discussed the background and experience of the firms' founders in the respective empirical chapters for each firm, and how it affected their decisions.

specifically for each project site, while similar turbines and packages of equipment can be used in gas power plants, reducing the amount of engineering work in each project. Deeper attention was therefore paid to operative functional SI capabilities in Farab.

The evidence shows the conditions in which Mapna initiated the accumulation of operative functional SI capabilities. Early activities started when the firm envisaged manufacturing gas turbines and engineering the core equipment block independently from Ansaldo. The initiatives were reinforced as Mapna decided to switch to Siemens's style in power plant engineering in order to create an advantage in the local market of the electricity sector. The CEO of the firm insisted on accumulating the related attributes for this purpose despite some initial opposition by the firm's engineers. His role was also evident in the subsequent development of NIAM, Mapna's standard design for gas power plants.

Another issue emerging from cross-case analysis is that several instances of modifications in non-core equipment were observed in the early projects of one firm, Farab, but not in the other. The evidence reveals that the early modifications in Farab were derived from cost-cutting motivations. The motivations had both internal roots, as senior management was concerned about costs, and external roots in the wider energy policy of the country. The strategy of the Ministry of Energy was to invest in thermal power plants in order to respond to the rapidly increasing consumption of electricity in the country. This policy adversely influenced the financial circumstances of hydro power projects. On the contrary, Mapna was less under cost pressure but under more pressure to finish projects quickly. The following discussions will reveal the effects of such pressures on the firm's strategies and the evolution of capabilities. Equally importantly, engineers in Farab had the confidence to carry out such modifications. This level of confidence was partly built through formal training programmes on turbine design in the early days of Farab's establishment and by the development of local engineers under the supervision of professional foreign engineers for learning the principles of engineering hydro plants.

Although both firms built the operative level of latecomer functional SI capability through packages of projects, the comparison reveals important differences in their learning processes. In both cases, the opportunity of simultaneously starting a number of projects, grouped into a package by the client, was utilised to create incentives for foreign partners in technology transfer. However, Farab had a systematic approach to learning, consisting of theoretical and vocational training on turbine engineering and assembling integrated teams of foreign and local plant engineers, while Mapna relied on gradual learning by copying engineering documents from previous projects, trial-and-error learning by local engineers and putting high hopes on the license it had acquired from Siemens. Mapna used its own power plants to create a test bed for this trial-and-error learning.

Cross-case analysis also helps us explain why a firm-specific standard design for gas power plants, NIAM, was developed by Mapna while Farab did not offer such standard designs. Apart from the technological impossibility of such designs in large hydro power plants, the evidence shows that Mapna reached that decision under the influence of various internal and external forces. Due to the rate of growth in local electricity consumption, Mapna was expected to finish an increasing number of projects quickly, near to the international norms of completion times. The inability of the firm to meet this time objective while performing full customisations for every project led to the strategic decision to minimise engineering activities and transform turbine manufacturing into a mass manufacturing mode. The development of NIAM was the result of this strategy.

8.2.2 Basic innovative level of latecomer functional SI

The comparison indicates that operational necessities initiated the accumulation of this level in both cases. As the evidence shows, neither of the firms had planned in advance to build this level of capability; instead, failures of the turbine and emergence of problems during the operation of installed equipment triggered the development of this capability. In the case of Farab, it started because of a disagreement with Siemens over the root of failures in an installed turbine. Similarly for Mapna, it started when unexpected problems emerged during the operation of its delivered turbines and resolving the failures was outside the license agreement. The operational need to model the exhaust of the gas turbine, in order to design the boiler in combined cycle plants, was another driver in Mapna. Both firms realised that this level of capability was necessary for providing after-sales services to clients[8] and for keeping up the firms' image.

The evidence also indicates that Farab started this process earlier because, purely due to luck, the failure of the turbine occurred earlier in time, but the opportunity was picked up by the motivated engineers and their initiative was supported by senior managers. Mapna, however, had relied on its agreements with Siemens for troubleshooting earlier events, and senior managers disapproved of the allocation of internal resources for such purposes, despite the

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[8] As described in the previous chapters, there was a local content law in the country that mandated the clients to source a minimum share of project costs from local suppliers and contractors. Since the monetary value of design contracts was tiny compared to the manufacturing of equipment, the law did not motivate firms and clients to focus on design capabilities from the outset.

requests of some engineers in Mapna. The prevalent technical perspective in Mapna was to seek solutions from leading systems integrators, avoiding the risks of local initiatives. This attitude changed as the firm's reputation became threatened by the emergence of failures, and its reliance on firms from abroad for resolving these failures was no longer reliable.

However, both firms later deliberately invested in the further development of this capability, mostly to expand their market possibilities. In the case of Farab, the initial attributes of this capability were therefore used to come up with cost-cutting innovations in an overseas project, and to prepare stronger technical proposals for overseas tenders. Similarly, Mapna envisaged expanding the market for its turbines by putting them into new applications and expanding its business into the operation and maintenance of local power plants.

The comparison shows that both firms discovered new local resources throughout the capability building process at this stage. The origin of accumulating this level in Farab indicates that it was impossible to rely on help from the leading systems integrator due to a conflict of interests. Likewise, the initial hopes of Mapna to receive support from Siemens were abandoned in the face of the challenges imposed by trade embargos and the genuine reluctance of Siemens on competitive grounds. As such, the strategy of reliance on local resources not only triggered the accumulation of deeper knowledge in engineering teams but also led to finding new resources within the national system of innovation, such as research centres and specialised suppliers for supporting the activities of measuring, modelling and analysis.

8.2.3 Intermediate innovative level of latecomer functional SI capabilities

The local client's refusal to accept the commercial risks of locally designed hydro turbines was one factor delaying the progress of this level in Farab for a relatively long time. Evidence shows that Farab proposed to its local client in 2000, seven years after the company had been established, to design hydro turbines provided that the client promised enough orders to justify the required investments. This suggestion was based on the accumulated level of confidence of the engineers in overcoming the challenges of hydro turbine design. This suggestion was not, however, accepted by the client because of the commercial risks and expectations of performance of the local turbine. The client demanded turbines with very high efficiency in energy conversion, which was hard to achieve locally at that stage. Despite the lack of support from the local client, engineers in the firm continued the quest to find answers to the questions in their minds about why the shape and design of turbines were so different across projects. This curiosity led to the gradual accumulation of certain attributes for turbine design capability, such as scientific equations, tacit knowledge of design processes and firm-specific computer applications for modelling and analysis.

However, the firms' strategies eventually became the significant driver for the build-up of this level of capability in both firms. As the evidence shows, Farab had designed two hydro turbines at the time of fieldwork but neither of them had been manufactured. Similarly in Mapna, the initiatives for turbine design and turbine modification had started, but had not yet produced concrete results. As such, the discussions in this section mostly relate to the drivers and motives behind the decisions of these firms to invest in the journey.

Farab's decision to design a small hydro turbine was largely aimed at protecting the firm's image against the allegations of the local client about the weaknesses of Farab's engineering capabilities. In addition, the firm chose to start the turbine design to open up opportunities for the development for its motivated engineers. The experience of the firm in international markets also illuminated the strategic importance of turbine design capability. As for the case of Mapna, the strategy of the firm to cope with local competitive threats was to expand its advantages by means of modifying turbines and resolving sophisticated technical problems during the operation of plants. Recently, new trade embargos on Iran have motivated local clients to support the further development of this capability in both firms.

Despite the differences, there are significant similarities in the process of building capabilities in the two firms. The evidence reveals that both firms have financed the process from internal resources. Farab designed the small turbine to be used in its own plant and the money for the design and prototyping of the second turbine was secured from internal funds. As for the case of Mapna, the related projects are financed by the firm's R&D budget and the modified turbine is anticipated to find a large local market. Another significant similarity is that both firms have employed new individuals for this purpose from local industries and research centres with backgrounds in similar technological domains.

Farab has relied on its own engineers for turbine design and they have filled their knowledge gaps through carrying out research, while the evidence shows that Mapna has arranged formal collaborations with foreign partners. In addition to the technological characteristics of the product as a partial explanation for this difference, the firms' current status in terms of capabilities and their strategies can provide further explanations. As the evidence indicates, the design of hydro turbines depends to a large extent on the experience of designers in understanding the emergent behaviours of turbines and their tacit knowledge in devising an appropriate shape for turbine blades. On the contrary, although the principles of turbine design and improving turbine performance are relatively more codified in gas turbines, complementary technologies, such as suitable materials, to realise the improvements are high-technology and often block advancements in this area. Mapna prefers to acquire knowledge on options and suppliers of complementary technologies from professional designers instead of through independent exploration.

Latecomer project SI capabilities

As Figure 8-3 and Figure 8-4 show, Farab has built its basic level of project capabilities and has recently started to develop the intermediate level for this capability. Meanwhile, Mapna has matured its basic and intermediate levels of project capabilities. The path leading to the current status, however, has not been in a deterministically upward direction in Farab. Project capability remained stable over a considerably long time as internal ambitions to progress waned when key individuals left the firm and the local client was satisfied with the status quo of project management due to its inability to finance fast-track projects. The following sub-sections provide cross-case comparisons at each level of capability depth.

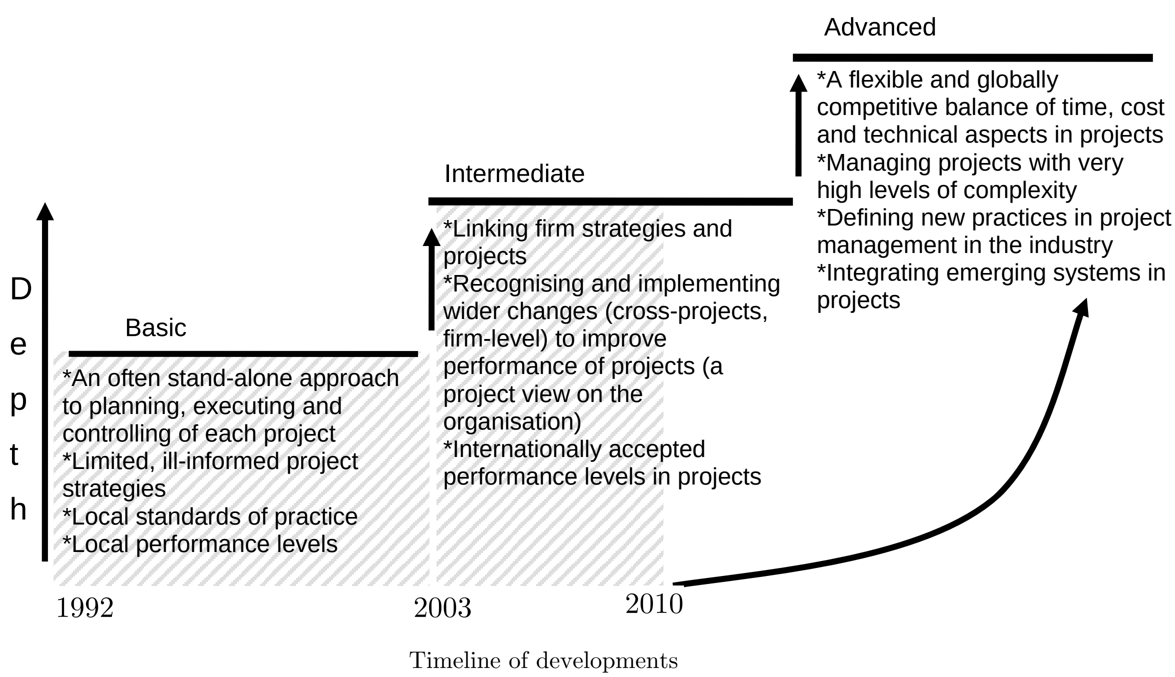

Figure 8-3: the evolution of latecomer project SI capability in Farab: project part.

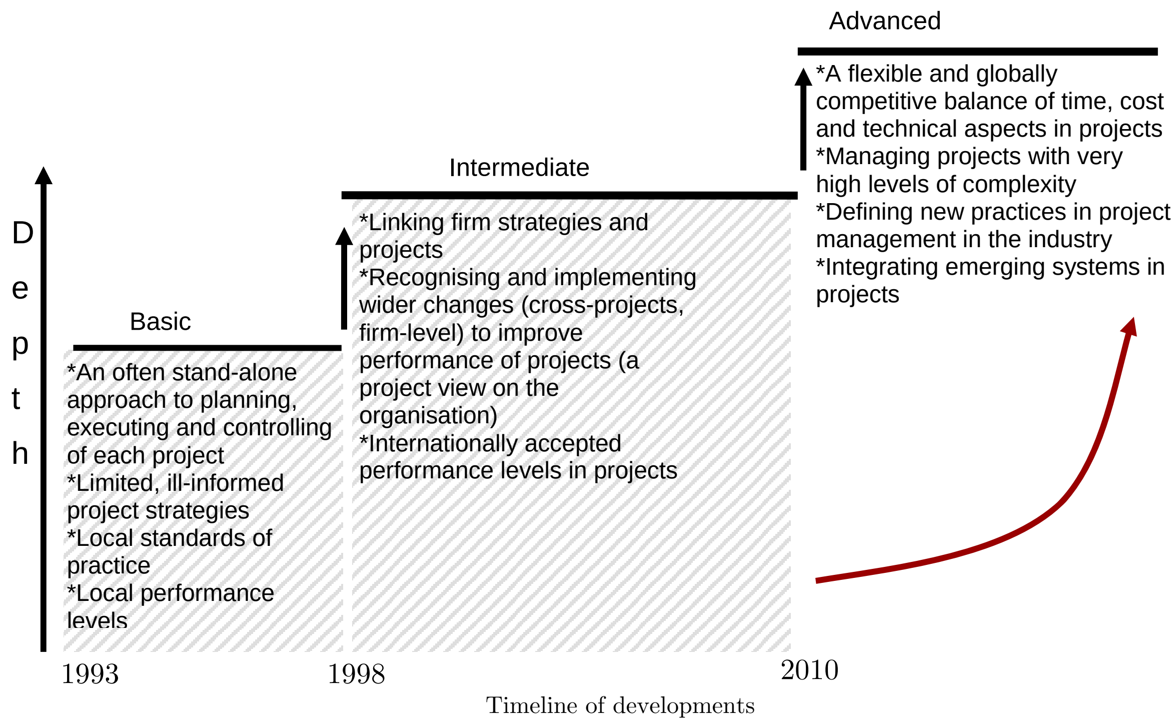

Figure 8-4: the evolution of latecomer project SI capability in Mapna: project part.

8.2.4 Basic level of latecomer project SI capability

In comparison, one of the companies relied to a larger extent on learning from abroad at this stage. As the evidence reveals, the senior management team of Mapna believed that organisational capabilities for prime contracting should be learned directly from abroad, while the perception of the team in Farab was to rely on internal deliberations and the experience of the team. As such, Mapna learnt a wider range of attributes, such as process knowledge and software applications, underlying project capabilities from abroad at the outset and then through its cooperation with leading systems integrators in subsequent stages. Despite this difference, both firms have deployed organisational arrangements to continuously improve upon their initial attributes and have eventually developed their own firm-specific project capabilities.

The cross-case analysis reveals that Farab was comparatively late in building some attributes for the basic and intermediate levels of project SI capability such as mechanisms for time and cost control. Mapna, however, developed these attributes formally in its early stages. The evidence indicates some factors behind the late developments in Farab. Firstly, the unique technical specifications of each hydro power project made the population of a database on time and cost of project tasks and comparing them across projects difficult. Secondly, the lack of support from managers suppressed the early initiatives of motivated individuals in the central Project Control Department in this direction, eventually leading to project planning being devolved to project teams and those individuals subsequently leaving the firm.

8.2.5 Intermediate level of latecomer project SI capability

The leadership of the firms was a major factor behind the differences between the two firms in progressing in this capability. Identifying the outlook of the large local electricity market, the senior management team of Mapna envisaged reducing the risks of managing future projects by vertical integration along the value chain of the industry. Similar discussions developed in Farab and the lack of a promising outlook in terms of demand was put forward as a justification against integration. However, in retrospect, some senior managers of Farab blame the decision on low risk-taking attitudes prevalent among Farab managers. The evidence also reveals that the demise of a central planning/control mechanism for reflecting on patterns across projects and for pushing forward improvements across projects slowed down the process in Farab.

The cross-case analysis reveals that the demands of new clients outside the traditional local electricity market induced the build-up of this level of capabilities in both firms. The deliberate strategy of local clients to promote competition from new local contractors and the intrinsic decline in the number of possible sites of new hydro power plants in Iran, combined with inspirations inside the firms for growth motivated them to search for new local and international markets. The sophisticated demands of new clients in terms of shorter project durations, an integrated strategy in project definition[9] and asking for some organisational requirements through qualification processes induced both firms to accumulate higher-level attributes underlying project capabilities.[10]

Furthermore, deliberate changes to the structure prepared the grounds for continuous improvements in both cases at this level. As the evidence shows, continuous improvement schemes such as EFQM and ISO Quality Assessments have formed an important part of building attributes at this level. Dedicated organisational resources were created in both cases for the systematic identification of challenging areas and the implementation of improvements. These organisational resources were created through the restructuring programme in Mapna and a managerial change within the existing department of Farab.

[9] By 'the strategy of project', we mean how work packages were divided, for instance whether civil and equipment works were awarded in one integrated contract or whether projects were defined as turn-key schemes or BOO and BOT.
[10] Working with overseas clients permitted the firms to monitor the practices of their competitors and get evaluations from clients who had experience of working with those competitors.

8.2.6 Latecomer pre-project capability

As Figure 8-5 and Figure 8-6 illustrate, both firms have accumulated the basic and intermediate levels of pre-project capability. Although development of latecomer functional SI and project SI capabilities in Mapna have created some market opportunities, the systems integration capability of the firm has advanced around a certain technology of gas power plants and based on a certain approach to minimising engineering activities in projects, both of which potentially create limitations in other markets.

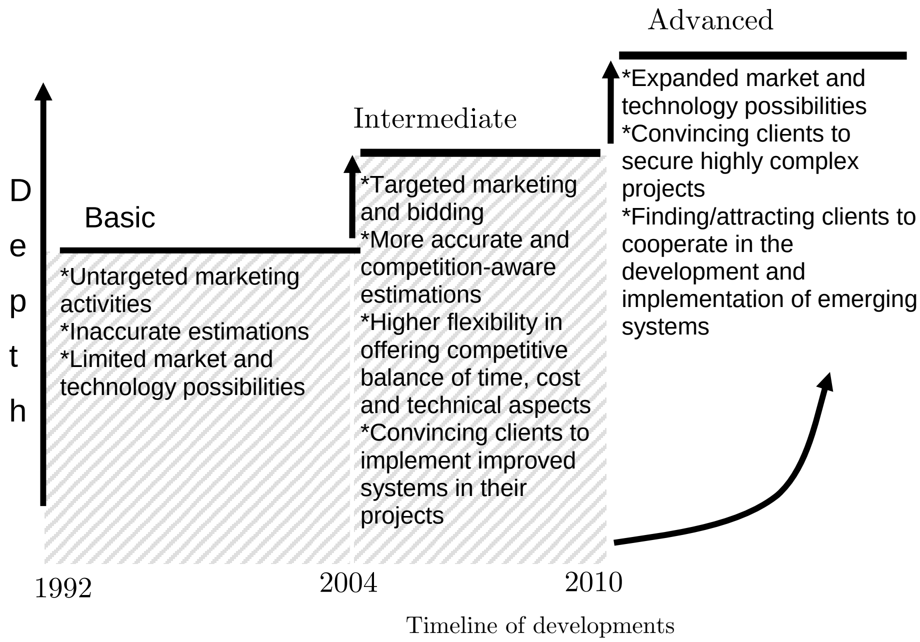

Figure 8-5: the evolution of latecomer project SI capability in Farab: pre-project part.

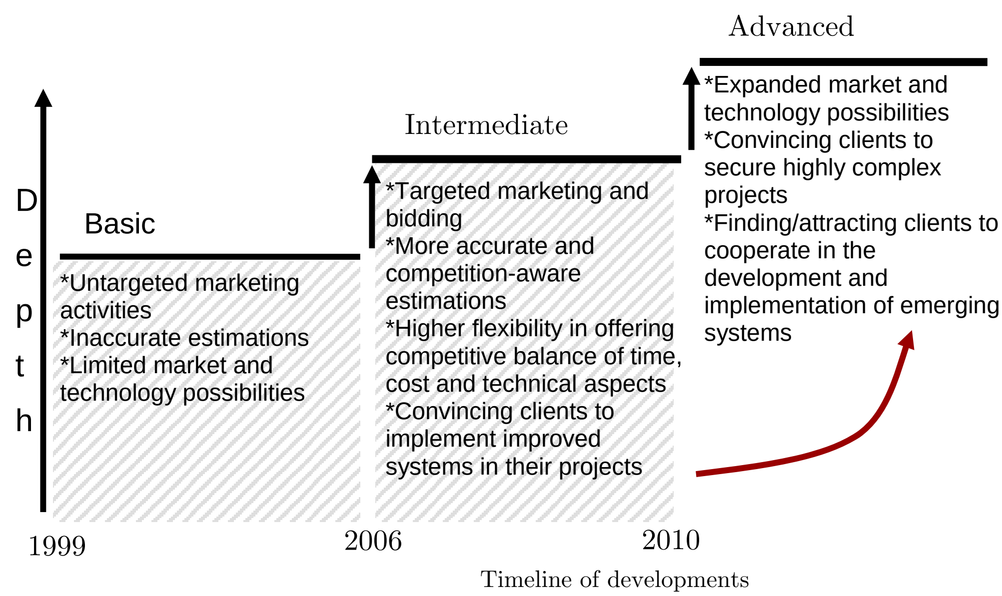

Figure 8-6: the evolution of latecomer project SI capability in Mapna: pre-project part.

In both cases, the forces of competition were major drivers behind the development of pre-project capabilities. The development of the attributes underlying pre-project capabilities were initiated when the firms were exposed to competition in the local electricity market. The early transformation processes were based on the internal activities of the firms to improve estimations and to utilise accumulated experience of managing previous projects. Pre-project capabilities improved as the firms participated in more competitions and reflected on the performance of bids. The firms also deployed more formal structures and processes for pre-project activities in areas such as gathering information on markets and competitors. Nevertheless, further progress at this stage depends to a large extent on progress in functional and project SI capabilities. As the evidence shows, it was the advancement in project capabilities and functional capabilities that enabled the firms to understand the technical requirements of their clients, to prepare better technical proposals, to commit to challenging project times and to improve their estimations.

8.2.7 Latecomer post-project capabilities

As Figure 8-7 and Figure 8-8 show, both firms have accumulated the basic level of post-project capabilities and have created some attributes for its intermediate level; however, full realisation of the intermediate level depends on advancements in functional SI and strategic SI capabilities to utilise the feedback from the post-project phase for improvements.

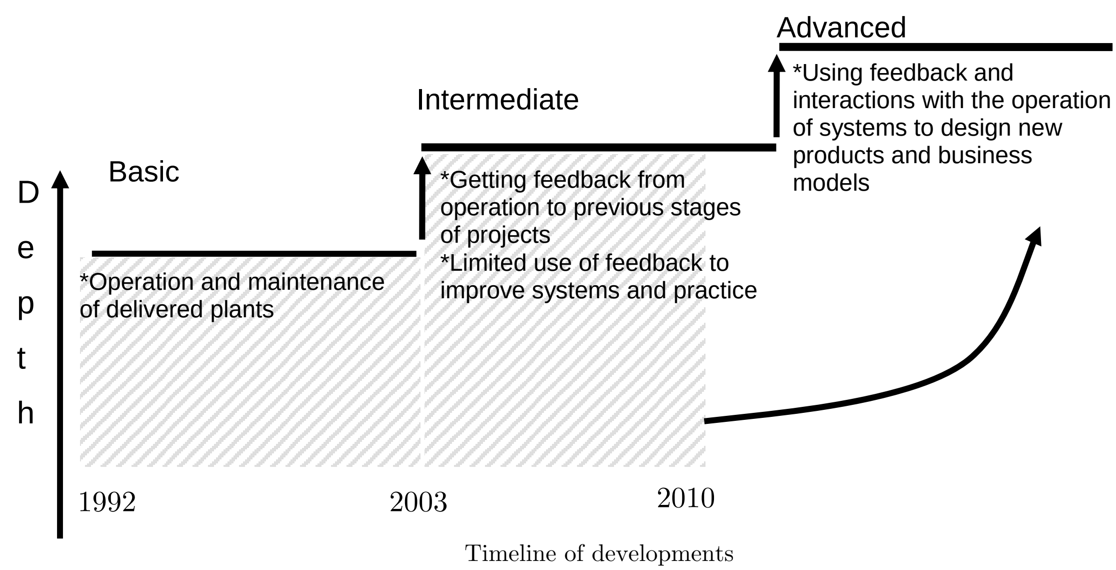

Figure 8-7: the evolution of latecomer project SI capability in Farab: post-project part.

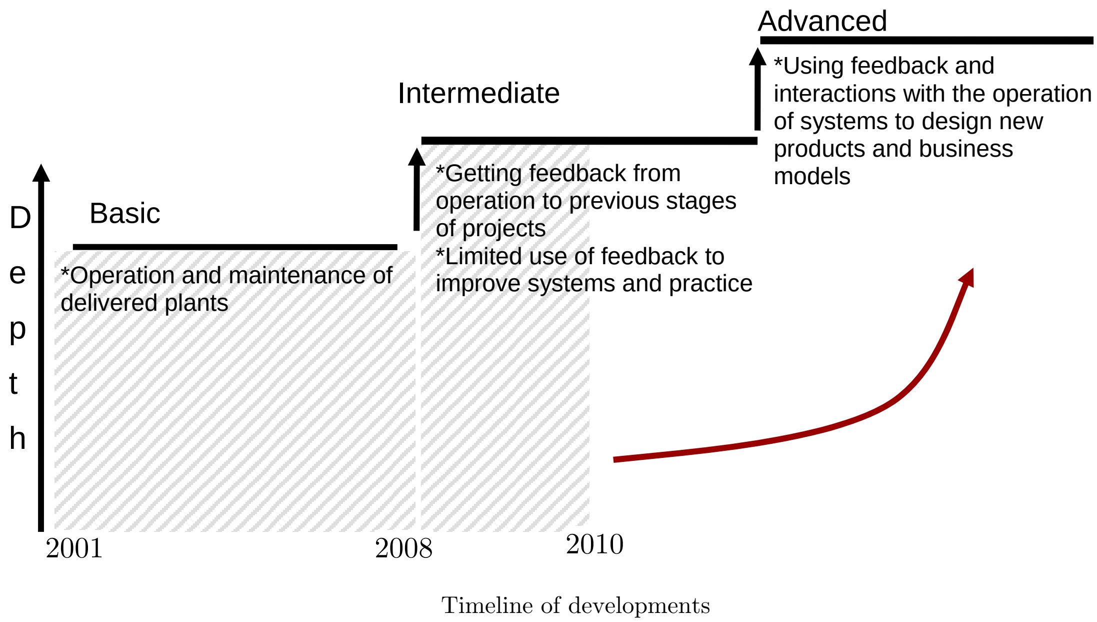

Figure 8-8: the evolution of latecomer project SI capability in Mapna: post-project part.

The local clients' strategies and the technological characteristics of the products influenced the commercial feasibility of post-project activities in the two cases. Terms and conditions set by the local clients in the contracts to operate hydro power plants made the business commercially unattractive for Farab. Nevertheless, the firm proposed to the client to operate the plants to protect its image against accusations that failures during the operation of delivered plants were faults of Farab. On the other hand, gas-fired power plants require frequent maintenance of turbines and changes of blades, promising a good market for selling equipment manufactured by Mapna.

The cross-case analysis shows that some attributes underlying the basic level of post-project capability, such as experience of operation and technical knowledge of troubleshooting, were acquired through carrying out other project tasks, such as operation of the plants during the trial-run period in projects or usual power plant engineering tasks. The establishment of an O&M division by Mapna enabled the firm to attract skilled operators and managers of plants from around the country.

Internal commitments were behind the creation of formal mechanisms for collecting feedback from the later stages of projects. In both cases, the firms' decision to improve power plant engineering resulted in creating an Engineering Office on project sites to collect feedback throughout the construction and erection period.[11] The attention to collecting feedback was in part forced by the requirements of ISO Quality Management Certificates.

The mechanisms for collecting feedback were, however, necessary yet not sufficient attributes for building the intermediate level of post-project capability. As the evidence indicates, complementary functional and strategic SI capabilities were required in the engineering and manufacturing divisions of the firms to analyse the feedback and implement the improvements implied by them.

8.2.8 Latecomer strategic SI capability

As Figure 8-9 and Figure 8-10 indicate, both firms have developed the basic level of latecomer strategic SI capability and have embarked upon building the intermediate level. Mapna has established formal organisational mechanisms underlying this level and its senior management team has shown a higher commitment to continuing with the related investments.

[11] The offices also resolve minor technical issues that arise during the construction work.

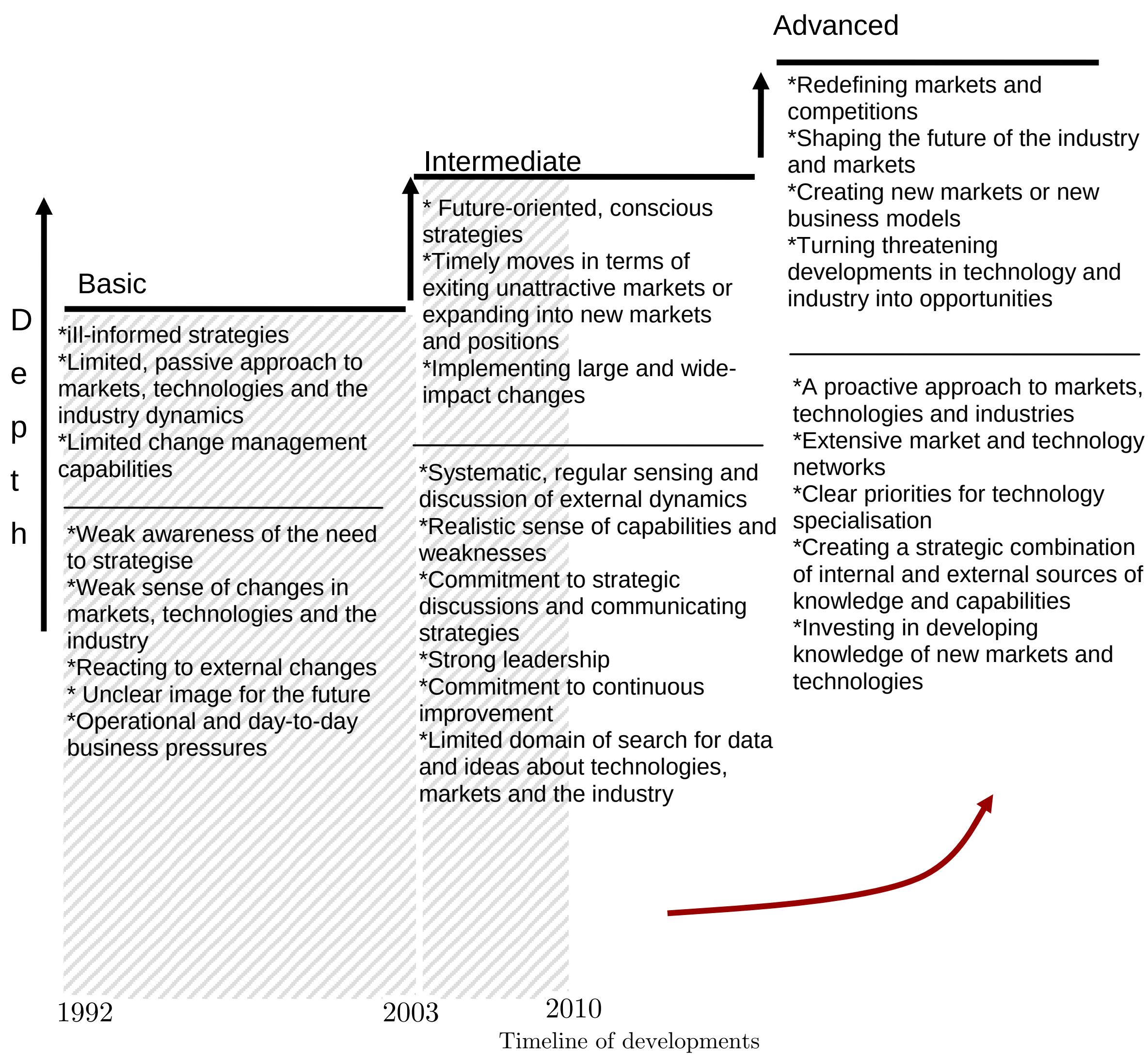

Figure 8-9: the evolution of latecomer strategic SI capability in Farab.

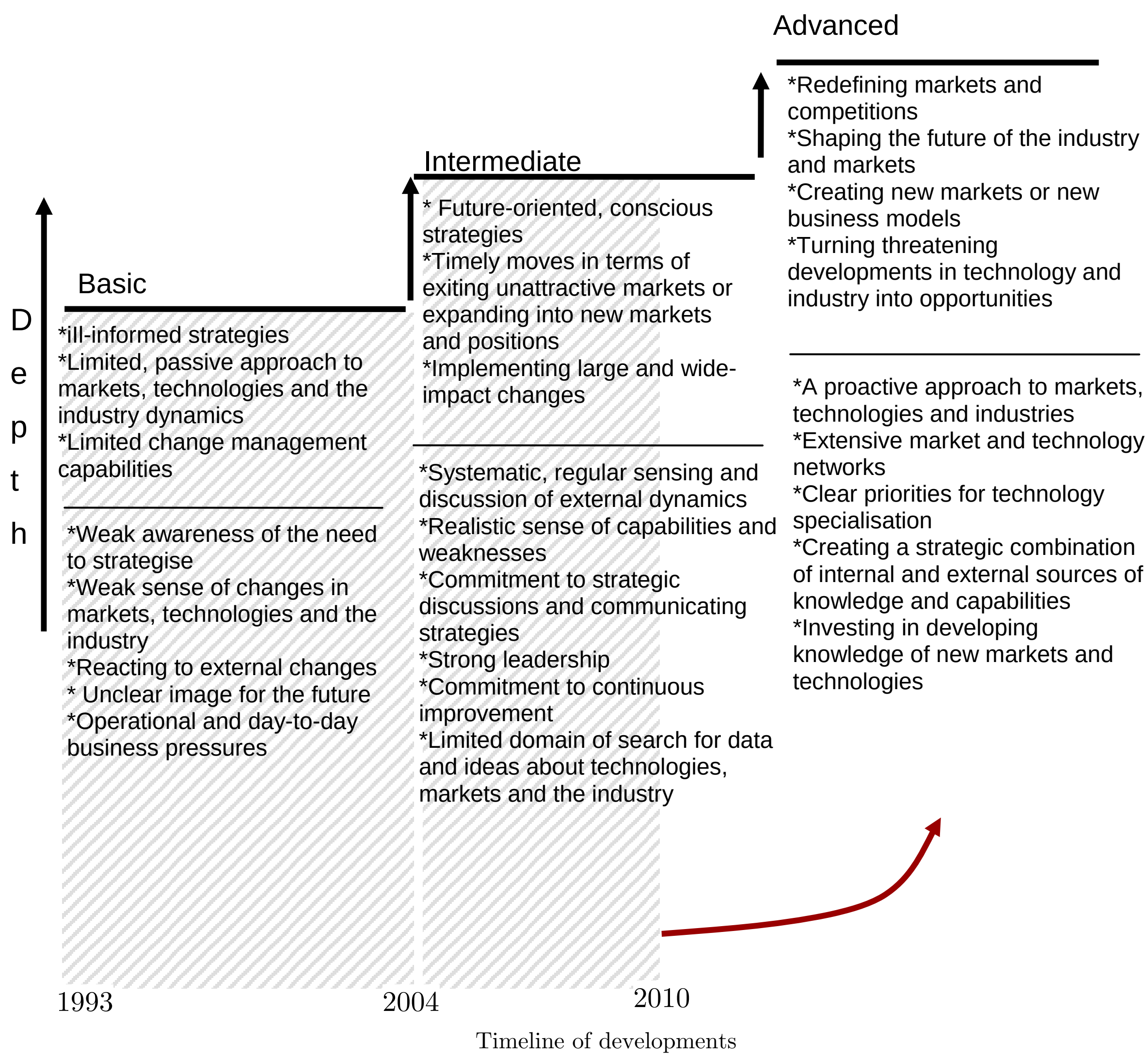

Figure 8-10: the evolution of latecomer strategic SI capability in Mapna.

The comparison shows that neither of the firms had envisaged the observed developments in LSIC from the start. Both firms were established to manage power plant projects in the local electricity market, initially lacking a vision to compete in overseas markets. The evidence indicates that progress in the three core constituent parts of LSIC, specifically in functional and project capabilities, occurred in response to developments in the external environment and the evolution of aspirations and attitudes inside the firms.

Some dedicated organisational resources were gradually built in both firms for sensing and discussing the changes in markets and technologies, assessing internal aspects of the business and envisaging and implementing related improvements, as attributes underlying the intermediate level of strategic SI capabilities. In both cases, assessments and improvement activities related to ISO Quality Management Certificates and EFQM Awards had built some initial attributes, but further development of attributes took place through the creation of organisational resources to focus on the identification of and drive for improvements. These resources were created as a result of a restructuring programme in one firm and a managerial change in the existing department of the other firm.

In comparison, Mapna built more formal structures and processes underlying strategic SI capabilities. Evidence reveals that the development of these attributes was induced by the emergence of complexities in the management of the expansion of Mapna and threats in its local market. The CEO of Mapna pushed for the establishment of these mechanisms.

8.3 Interpretation of findings across the three core constituent parts of LSIC

8.3.1 On the similarities and common patterns

Pathways of evolution

Some common patterns were observed in the overall pathways of LSIC evolution, even though each case showed some distinctive aspects in timing, the rate of progress and the direction of development. The staircases shown in Figures 8-1 to 8-10 depict the common patterns in the evolutionary path of LSIC in our study. In addition to the overall pathways, the development of functional SI capabilities had other significant similarities in the two firms. Both firms started from smaller scale innovative activities in the non-core equipment (or the non-core equipment block) of a power plant and progressed towards more sophisticated and risky changes in core equipment (or the core equipment block) that required attributes such as knowledge, software and tools of a more sophisticated nature to underlie capabilities. The developments at the basic and intermediate levels of functional SI capabilities were permitted by financial resources that were internal to the firms and both firms used the power plants that had been financed, partially or fully, by their own resources for tests and trials that were required in the development of functional SI capabilities.

However, the development paths were not linear in an upward sense. For instance, progress in project SI capability in Farab paused for a relatively long period of time, and the capabilities for customising each plant were gradually downgraded over a period of around four years as Mapna chose to propose its own standard design for gas-fired power plants. Furthermore, Mapna invested simultaneously in building basic innovative and intermediate innovative levels of functional SI capabilities.

The evidence reveals that both firms had a complicated multi-dimensional agenda during their growth which affected the rate and direction of LSIC evolution. They started as agents of the Ministry of Energy in promoting the share of local content in projects. Coordination of the learning and upgrading activities among local contractors, as our evidence illustrates, took a certain share of the firms' organisational resources which otherwise could have probably been allocated to initiatives strategic to the firm, such as reflecting on conditions for a sustainable growth in capabilities.[12] On the other hand, the firms built LSIC while they were under pressure of managing several projects concurrently to respond to the rapidly growing electricity consumption in Iran. Although having these packages of projects contributed to the development of capabilities by providing incentives for international knowledge transfer agreements, the overwhelming volume of project tasks was shown to militate against ensuring a sustainable growth of capabilities.

Transformation processes

Both firms acquired initial human resources, underlying early levels of LSIC, from the local pool of university graduates or candidates with experience in previous power plant projects in Iran, experience in the operation of plants or experience in other local industrial projects. Although the firms initially received inputs, such as knowledge and computer applications, to build their capabilities from leading systems integrators, the transformation processes shifted from an emphasis on overseas sources towards increased reliance on sources within the firms and in the local context as they progressed on their capability building journeys. For instance, the context leading to the accumulation of basic innovative functional SI capabilities in Farab indicates that it was difficult to rely on help from the leading systems integrator due to conflicts of interests. Likewise, Mapna's initial hopes to receive support from Siemens in the analysis of failures of the delivered turbines were abandoned in the face of trade embargos and also the genuine reluctance of Siemens on competitive grounds.

Considering this context and status of capabilities inside the firms, both firms chose to rely on local sources which not only resulted in the accumulation of deeper knowledge in engineering teams but also led to finding some helpful resources in the national system of innovation, such

[12] As our previous discussions show the use of local content in projects was economically attractive.

as research centres and specialised suppliers, to support measuring, modelling and analysis activities. These possibilities were previously unknown to the firms.

The following table categorises the transformation processes observed in these latecomer cases into two broader groups based on whether the transformation process was observed in functional SI or in the other two constituent parts of LSIC. The assumption behind this classification is that the former capabilities have a more technological nature, while the latter are more of an organisational nature, although organisational capabilities are often inseparable from and indispensable to technological capabilities. This classification aims to reveal further insights from the cross-case analysis.

Mainly technological	**Mainly organisational**	
Latecomer functional SI capability	Latecomer project SI capability	Latecomer strategic SI capability
•Employing supervisory services from leading firms •Analysing failures of equipment •Contemplating various designs •Learning through projects •Trial-and-error learning •(Theoretical and vocational) training •Learning from (local/international) competitors, contractors or suppliers •Licensing •Hiring experienced individuals •Continuous improvement, learning by doing	•Employing consultancy and supervisory services from leading firms •Learning from (local/international) competitors and suppliers •Trial-and-error learning •Training •Learning through projects •Hiring experienced individuals •Licensing •Continuous improvement and learning by doing	•Changes in structure •Leadership development •Continuous improvement •Hiring consultancy services •Strategic deliberations in committees or groups •Learning from (local/international) competitors and suppliers •Vision development and communication •International business benchmarking (formal and informal) •Experience of participating in new markets and competitions •Developing formal

		structures and processes for sensing, deliberation and decision-making

Table 8-1: Transformation processes in the observed evolution of LSIC

As Table 8-1 illuminates, if we put latecomer project SI and latecomer strategic SI under the broader category of mainly organisational capabilities, several similarities emerge from the analysis of these transformation processes.

The elements of continuous improvement[13] appeared in several forms, such as gathering and acting upon feedback, reflecting on patterns across projects, analysis of successes and failures, identifying improvement opportunities by utilising proper planning and control mechanisms in projects and a commitment to defining progressive challenging goals. However, realising the improvements occasionally required far-reaching changes across the whole organisation and further developments in a set of related capabilities, necessitating a high level of commitment in the organisation and a strong strategic SI capability.

Learning through projects appeared significant in the development of LSIC. Both firms accumulated initial levels of functional and project SI capabilities through early packages of projects, although each of them pursued its own avenues for acquiring the micro-attributes underlying those capabilities. Moreover, project and functional SI capabilities were enhanced by experiencing and resolving a new set of challenges in each project. Working with various turbine technologies in Farab and contemplating the unique style of advanced designs by Farab's engineers strengthened the capabilities to understand complex technologies and led to the accumulation of some attributes for intermediate innovative functional SI.

Learning from local/international suppliers and contractors (sometimes competitors in other projects), whether leading suppliers such as Siemens or smaller specialised suppliers in project tasks, was significant in accumulating attributes across the three core constituent parts of LSIC. This learning appeared in several forms such as borrowing ideas and building attributes underlying capabilities through formal transfer agreements with leading firms or as by-products of such formal activities. Particularly in Mapna, formal agreements were permitted

[13] As Bessant and Caffyn (1997) point out, 'Continuous Improvement' is a widely-used concept with various meanings. Our understanding of this term is very close to that of Gilmore (1990) as: "the integration of philosophy, techniques and structures to achieve sustained performance improvements in all activities on an uninterrupted basis."

by a growing local market and the client's policy of dividing the aggregate demand into packages of projects.

Seeking international benchmarks provided some inputs into the transformation processes of various aspects of latecomer systems integration capabilities. The evidence indicates that such benchmarks not only provided ideas for improvements but also adjusted the aspiration level (Winter 2000) in the accumulation of capabilities and helped the firms to overcome mental barriers. Mapna borrowed several ideas from Siemens and GE to enhance its capabilities in project, pre-project and functional SI capabilities. Similarly, its efforts to finish the first power unit of projects in 18 months was a time record that Mapna achieved in cooperation with Ansaldo in the past, which inspired Mapna to repeat it independently. Farab became exposed to international benchmarks of project management later than Mapna. Realisation of the promise by a foreign competitor to finish a hydro power project in a considerably shorter period of time compared to Farab's standards broke the mental barriers of Farab's engineers that had blocked the progress of project management capabilities in the firm. This change happened a decade after the firm had been established.

The evidence indicates the importance of learning from technological failures of equipment and from unsuccessful market attempts in the enhancement of LSIC. Analysing technological failures of a hydro turbine through an independent step-by-step trial-and-error effort by Farab led to the accumulation of advanced modelling and simulation knowledge, a better understanding of turbine behaviour, and the identification of design-related capabilities in the national innovation system. This effort increased the level of self-confidence in the firm and led to the discovery of the initial tacit knowledge for the turbine design process. In retrospect, engineers analogised those cases of failure analysis to a university, reflecting the plethora of learning opportunities offered by them. Similarly, reflecting on the performance of bids demonstrated the strategic necessity of building higher levels of functional SI capability for achieving success in overseas markets.

The national system of innovation also fed into the transformation processes of LSIC. Both firms acquired capable human resources and some knowledge elements underlying basic and intermediate innovative functional SI capability from local research centres, universities and other related industries. For instance, Farab hired a designer from a local firm specialising in the design and manufacturing of hydro pumps to strengthen its turbine design team. Similarly, Mapna hired human resources from the local aviation industry with experience in sophisticated modelling and analysis of similar equipment. Interestingly, the firms realised these potentials in the local system when incidents forced them to look for them. Apart from functional SI capabilities, Farab undertook learning from other local contractors to build intermediate level of its project SI capability.

Co-evolution of capabilities

The three core constituent parts of LSIC co-evolved and fed into each other through the observed evolutionary paths. Several instances were demonstrated in which strategic SI capabilities fed into the development of pre-project, project, post-project and functional capabilities. Strategic decisions to vertically integrate along the value chain, to transform turbine manufacturing into a mass manufacturing mode and to restructure the organisation affected the evolution of functional SI capabilities, project, pre-project and post-project capabilities in Mapna. Similarly, the strategy to enter into new local and overseas markets was shown to impact the accumulation of intermediate levels of pre-project, project and functional SI capabilities in both cases. The commitment to continuous improvement, as a component of strategic SI capabilities, fuelled progress in the three core constituent parts of LSIC.

Looking across to the other constituent parts of LSIC, the progress towards higher levels of post-project and pre-project capabilities depended on the advancements in functional SI capabilities for understanding the technological needs of clients, preparing competitive proposals and acting upon feedback. Likewise, the growth in functional SI capabilities, particularly at the basic innovative and intermediate innovative levels, expanded market possibilities. Pre-project capabilities were also important to securing new projects, the lifeblood of a project business, in order to bring in financial resources essential to sustaining the growth of capabilities.

The evidence reveals that micro-level attributes underlying one specific capability can be built through activities pertaining to other capabilities. Some attributes underlying intermediate innovative functional SI capability in Farab, such as scientific principles governing system behavior, tacit knowledge of modelling and firm-specific applications for design, were built during the analysis of failures in the complex equipment of plants. Likewise, some attributes that were accumulated through the repetition of design review and the engineering of power plants, such as understanding the behaviour of complex systems, experience of using different technologies, and knowledge of how designed systems work in practice, were used by Farab for the conceptual design of hydro plants. Some attributes for post-project capability, in both cases, were partially built through the trial-run operation period of plants that constitutes a part of almost every power plant project management contract.

8.3.2 On the differences in progress of LSIC

Despite the similarities and common patterns discussed above, each firm showed a distinctive level of achievement in the accumulation of capabilities, and distinctive timing and direction of progress across the three core constituent parts of its LSIC. The major differences are established in this section.

Level of capability	Operative	Basic	Intermediate	Advanced
Functional SI			M........................	..F
Project SI	NA		F.............M	
Strategic SI	NA		F............M	

F=Farab M=Mapna NA=Not Applicable: the level is not applicable for that particular capability

Table 8-2: Comparison of overall achievements in the accumulation of LSIC.

As Table 8-2 depicts, neither of the firms, at the time of research, had achieved the advanced innovative level of functional SI capabilities, although, according to our framework, Farab had progressed further in this journey by building up certain attributes underlying the advanced level, attributes such as some tacit knowledge of turbine design, knowledge of materials, sophisticated applications for modelling and analysis of the turbine and experience of prototyping its own design of a large turbine. In terms of project SI capabilities, Mapna had already matured to the intermediate level while Farab was still progressing in this level. For strategic SI capabilities, both firms were in the process of accumulating the intermediate level, although Mapna had progressed further by developing some formal mechanisms for sensing, analysing and acting upon strategic signals, as underlying attributes of the intermediate level of strategic SI capabilities. The entire set of LSIC in Mapna, however, was built around one specific technology of gas turbines, which potentially constrains the success of the firm in competitive markets.

As the evidence reveals, the priority of Mapna, until recently, was to progress in project SI capabilities, while Farab was more concerned with functional SI capabilities, accumulating the basic innovative and intermediate innovative levels of functional SI capabilities earlier than Mapna. An unfortunate turbine failure that happened in the early projects of Farab was investigated by the firm's engineers, building some initial components for basic functional capabilities. These attributes were further developed by enthusiastic engineers, with the support from the senior management, and eventually led to accumulation of some of the attributes, such as knowledge of the turbine design process, underlying intermediate innovative functional SI capabilities. Similarly, an earlier exposure to competition in the local market induced earlier developments in the pre-project capabilities of Farab. On the other hand, Farab had a comparative delay in maturing its basic project SI capabilities and in moving towards the intermediate level.

To answer why such differences emerged, we will need to understand how the evolution of LSIC proceeded in each firm; in other words, to understand the dynamics that shaped the firm-specific paths of LSIC evolution. These dynamics and the variables underlying them have been discussed unsystematically throughout the previous sections. The following section organises the evidence and provides further conceptual analysis.

8.3.3 Dynamics of LSIC evolution at the firm level

As illustrated throughout this chapter, LSI capabilities evolved in response to the myriad changes in factors internal to the firms and external forces, in that a complex interaction of such factors was behind every step on the path. This section organises the evidence and shows how some of the variables related to each other, constituting major variables, and how these major variables affected the paths. As the analysis shows, although external forces and the technological characteristics of the products provided the signals for change and created opportunities or restrictions for development, the status of the firms' LSIC was a major variable that shaped their responses to these dynamics.

External forces or signals

Local market: size, the extent of competition

The protected local market supported the initial growth of LSIC in both firms. However, the perceptions of the senior management teams about the condition of the local market in the long-term affected the commercial risks of further development of capabilities at later stages. In particular, Mapna secured its access to some project resources through vertical integration along the value chain of the industry, perceiving a growing local market.

The comfort of a secure local market in the electricity sector, however, did not motivate the build-up of attributes in functional SI, pre-project and project capabilities necessary for competitive success. The balancing effect of introducing competition from local contractors in later stages prompted a new era of accumulating higher-level attributes across the three core constituent parts of LSIC in Farab and Mapna. In both cases, the rise of local competitors was partly permitted by firms' strategies in outsourcing previous work packages, but was mainly supported by the local clients. As the evidence shows, forces of competition appeared influential in accumulating the intermediate and advanced levels of LSIC, while the previous levels had been built in the absence of competition.

Clients and the sophistication of demand

The above paragraph illustrates how controlling the extent of competition in the local market by local clients influenced the direction and timing of developments in LSIC.[14] For instance, the introduction of competition in the local hydro plant market in 2001, compared to 2004 for Mapna, caused an earlier accumulation of some pre-project capabilities in Farab. Similarly, the forces of competition, although introduced at different times in each case, caused investments in strategic SI capabilities when both firms performed formal strategic planning activities, went through organisational changes and new strategies were formulated to explore overseas markets. More importantly, the policy of the Ministry of Energy to respond to the growing consumption of electricity in Iran by favouring thermal plants over hydro plants meant that fewer financial resources existed for the latter market, which was one reason behind the motivations of Farab to cut their project costs, driving the development of its capabilities in certain directions and towards an earlier search for new markets.

From another perspective, the initial strategy of the local client of thermal power plants to aggregate the long-term demand into packages of projects facilitated the negotiation of knowledge transfer agreements by Mapna, and provided opportunities for the vertical integrations described above. On the other hand, the reluctance of the client to order locally-designed hydro turbines and its high expectations of turbine efficiency was one factor behind the delay in the development of intermediate functional SI capabilities in Farab for over eight years. Similarly, the strategy of the local client for hydro power plants to choose an independent contractor for dam construction in its projects allowed Farab to blame certain delays of its projects on the other contractor, one factor behind the late realisation of the drawbacks of its project SI capabilities. The terms and conditions of the local client for operating hydro power plants made the local operation and maintenance market commercially unattractive for Farab.

[14] It is not clear whether the local clients introduced the competition deliberately to enhance capabilities in the firms or if they introduced the competition to improve their own purchase terms and conditions.

From the perspective of clients' demands, the happiness of the local client with the project management performance of Farab did not induce the accumulation of intermediate attributes in its project SI capabilities for around 13 years. Interestingly, a higher sensitivity of the local client for thermal power plants to the duration of projects caused an earlier development of certain project SI attributes in Mapna. More sophisticated demands of new clients in terms of project management performance and technical requirements in both local and overseas markets led to the development of higher-level functional SI and project SI capabilities in both cases.

Accidents and the emergence of adverse circumstances

Both firms have records of failures or the emergence of problems in their installed turbines. The first failure in Farab was investigated by its motivated and able engineers, leading to the accumulation of some attributes underlying basic innovative functional SI capabilities. The management's trust in local resources enhanced over time as more cases of problems in the designs of leading systems integrators were spotted by Farab's teams. In contrast until recently, analysing and fixing accidents during the operation of turbines were outsourced to Siemens or to other overseas suppliers by Mapna. A combination of factors, such as the pressure of trade embargos, the gradual growth in self-confidence and capabilities, and the realisation of the importance of this knowledge to the competitive success of the firm, motivated Mapna to engage with such incidents and exploit their learning opportunities.

Contingencies in the international relations of Iran also impacted the direction of evolution and the nature of the transformation processes. The recent expansion of trade embargos and the imminent threat of wider-scope embargos convinced local clients to support the accumulation of intermediate innovative functional SI capabilities in both firms. Similarly, when Siemens pulled out from a technological cooperation project amidst new embargos, Mapna realised the possibility of relying on local resources, leading to the accumulation of higher-level capabilities in basic innovative functional SI.

On the other hand, the embargos blocked or at least made difficult access to certain technologies and suppliers. As such, a share of organisational resources had to be spent on finding alternatives and revising practices to minimise the negative effects of embargos on the everyday business of the firms, which otherwise could have probably been spent on more strategic aspects of LSIC development. Similarly, embargos blocked access to certain overseas sources of knowledge for building the intermediate innovative level of functional SI capabilities in Mapna. From a wider perspective, the dynamics of the international relations of the country provided changing signals for the firms in terms of which overseas markets they could penetrate.

Status of capabilities, particularly latecomer strategic SI capabilities

Strategic SI capabilities and the perceptions of managers about the status of other capabilities of the firms largely shaped the firm-specific paths through: (a) the distinctive way in which external opportunities and restrictions were perceived; (b) creating internal supports or drawbacks to evolution; (c) envisaging specific requirements for growth; (d) envisaging and implementing large-scale transformations in the organisation; (e) setting challenging goals; and (f) pushing for certain developments.

The strategies of the firms co-evolved with LSIC over time as the strategies were inspired and permitted largely by the achievements in LSIC while, on the other hand, the strategies directed and governed the accumulation of LSI capabilities, or, at least, the realisation of strategies required capabilities to be developed in certain directions. At the outset, both firms had an initial, partial understanding of the industry, especially in terms of the factors that lead to sustainable growth. This understanding grew over time and affected the priorities of change and capability building.

The lack of an initial intention, in both firms, to compete in international markets did not necessitate the development of high levels of functional and project SI capabilities. At the outset, there was no model or prior experience in local industrial sectors. This fact had an immediate impact on the confidence of the founders and policy makers in the success of the firms. However, more fundamentally, facing the challenges of designing the organisations, neither of the firms could fully comprehend the status of their counterparts in advanced countries, as the complexity of their organisations had evolved over a long history. The difference between the belief of leaders in the judgments and capabilities of their colleagues was a reason behind the adoption of an internal discussion approach to designing the organisation in Farab, and formal collaborations with foreign firms in Mapna. Interestingly, this difference in approach was sustained over time, as Mapna tended to rely on overseas sources for further growth of project, pre-project and strategic SI capabilities until recently.

The backgrounds of the senior management team, their understanding of the industry dynamics and their vision for the firm led to distinctive priorities for learning in each firm. Mapna paid more attention to project SI capabilities, while Farab invested more in functional SI capabilities. In Hughes's terms, the firms identified distinctive reverse salients during their growth. As such, the firms followed concentrated efforts to build more important capabilities and an independent, trial-and-error learning approach for other areas of LSIC. In later stages, forces of competition in the local market and the choice of the firms to expand into overseas markets caused their managers to revisit the assumptions of sustainable growth and to recognise the intermediate to advanced levels of functional SI and project SI capabilities as their main barriers to success, i.e. the emergence of new reverse salients, in Hughes's terms.

The effects that some weaknesses in the basic innovative and intermediate innovative levels of functional SI capabilities could have on the sustainable growth of capabilities had not been initially foreseen by senior management in either of the firms. A confluence of events in the external environment and the gradual progress in the firms' capabilities demonstrated the possibility and necessity of building those capabilities, although it was revealed at different times in each firm. Vision making was also significant in supporting or pushing for certain developments in capabilities. In Mapna, the leadership pushed the accumulation of operative and basic innovative levels of functional capabilities in recent years, insisted on developing the formal attributes underlying intermediate strategic SI capabilities, despite some internal opposition and set progressive challenging objectives for project management in the firm. In contrast, the lack of leaders' commitment in Farab was a major factor in slowing down for quite a long time the accumulation of micro-level attributes in project SI capabilities. The same effect was observed in Mapna when the senior management of the Turbine Manufacturing Division did not support the local engineers in an earlier development of basic innovative functional SI capability. In other words, the lack of basic innovative functional SI had not yet emerged as a reverse salient for the firm.

Personal characteristics of human resources, such as their self-confidence and ambitions, were also significant factors. Differences in the leaders' visions for the future and other personal entrepreneurial characteristics partly explain why Mapna undertook vertical integration across the value chain of the industry to secure access to project resources when the firm perceived some opportunities in the local market, while similar speculations in Farab did not end in vertical integration or other forms of securing access. In Mapna, the lack of self-confidence among engineers and managers was a major barrier that slowed down the potential build-up of the basic innovative and intermediate innovative attributes of functional SI capabilities at earlier stages. In contrast self-confidence was one reason behind the technological modifications in the early projects of Farab. Self-motivated engineers also initiated the build-up of basic innovative functional SI capabilities when an accident occurred in a plant and their curiosity, supported by the management, led to further progress in the process of designing hydro turbines.

Several instances have shown that strategic decisions on technology-related issues impacted the evolution of LSIC. Mapna's choice to develop LSI capabilities around one specific technology of gas turbine, which could also be described as a product-specific technology, led to the accumulation of limited[15] operative functional and project SI capabilities. Similarly, the strategy of the firm to transfer the production mode of turbines to mass manufacturing, in order to respond to the growing local demand, led to the downgrading of some attributes for customising power plants. On the other hand, the decision to break the reliance on Ansaldo for engineering core equipment and to break the reliance on Siemens for the analysis of failures in the operation of power plants resulted in developing the higher-level attributes underlying functional SI capabilities.

Strategic decisions on market issues were also revealed to have shaped the evolutionary paths. In both cases, the desire to sustain the position in local electricity markets and to expand into new markets inspired the accumulation of higher-level attributes in pre-project, project and functional SI capabilities. For instance, Mapna and Farab recognised that basic innovative functional attributes are required to offer technical services to turbines during the operation of power plants. In the case of Mapna, investments in the intermediate innovative level of functional SI capabilities were justified by the hope for opening up new possibilities in the local market, and the lack of an advanced innovative level of functional SI capabilities in Farab was identified as a barrier to success in international markets. In other words, the interaction of internal and external variables led to the recognition of different capabilities as distinctive critical problems in each firm, impeding its expansion.

The evidence reveals that deliberate changes to organisational structures can facilitate or hinder the development of LSIC. Changes of structure in project planning and control activities to an overly decentralised mechanism in Farab led to a relatively long pause in the identification and implementation of cross-project improvements. A managerial change in the related department and the adoption of a more centralised approach to the task revived the continuous improvement in this area later in time. From another perspective, changes in the structure allowed for the availability of dedicated organisational resources to reflect on and push for continuous improvements across the three core constituent parts of LSIC. In the case

[15] From a competitiveness point of view.

of Mapna, the recent restructuring of the firm facilitated the growth of pre-project, post-project and even functional SI capabilities by defining a new division of labour inside the firm. Similarly, in Farab, recent managerial changes in a department renewed the internal force for advancing strategic and project SI capabilities.

Operational goals to reduce the costs and duration of projects were shown to affect the direction of evolution. Cost reduction motives led to several innovative technological activities in the early projects of Farab. Later in time, the same drivers caused further utilisation of modelling and analysis capabilities in the Sangtude project, which led to the accumulation of attributes underlying higher levels of functional SI capabilities. In contrast to the cost-cutting motives of Farab, time-saving ideas induced several developments in Mapna. The development of a standard design for gas power plants and the transformation of the manufacturing mode of turbines into mass manufacturing aimed to reduce projects' duration.[16] The evidence has demonstrated several other instances in which Mapna changed its approach to the management of project tasks in order to reduce the duration of activities, despite the higher costs incurred by those changes.

Technological characteristics of the product

Differences in the technological nature of products affected the decisions relating to the rate and direction of evolution in LSIC. The technological possibility of offering a standard design for gas power plants, combined with the weak engineering capabilities of Mapna to respond in a timely way to the growing local market, induced the firm to develop its standard design, NIAM. NIAM proved to secure the position of Mapna in the local market but ultimately led to further weakening of its functional SI capability to customise each plant. The countervailing force of technological necessity for customising equipment in combined cycle power plants, however, induced the build-up of basic innovative functional SI capabilities in the firm.

In contrast, the necessity of engineering each hydro power plant according to its geographical site combined with the internal capabilities of the firm, motivated an earlier attention to building up functional SI capabilities in Farab. Contemplating the unique design of hydro turbines in every project was also shown to provide significant inputs into the exploration of tacit knowledge of turbine design in Farab. The evidence shows that the effects of the

[16] The effects of these developments on the evolution of functional SI capabilities have been discussed throughout this chapter.

technological nature of the product are not limited to functional SI capabilities. Gas power plants require constant maintenance and frequent replacement of turbine components compared to the relatively low maintenance technology of hydro plants. This opportunity was one reason that motivated Mapna to enter into this business in the local market. Although the technological characteristics of products affected the firm-specific evolutionary paths, the firms were not forced to stick to a particular product. They could change their product portfolio or enter into new areas to overcome the adverse effects.

8.4 Summary

The firms in our study were established by Iran's Ministry of Energy to replace the expensive international prime contractors of power plant projects in Iran's electricity sector. In less than 20 years, LSIC has evolved from small beginnings in low-cost project management capabilities to a situation of significant LSI capabilities underpinning national, regional and international successes in power plant projects and, more recently, in local markets for other complex projects. As such, the firms have gone well beyond the initial expectations and objectives of their founders.

At the outset, there was no local experience in systems integration of large-scale complex projects, casting shadows of doubt over the success of both firms within the industrial sector of Iran and even within the Ministry of Energy itself. The surprising progress of these firms through time, however, has inspired the establishment of similar companies in other project sectors, most notably PetroPars and Oiec companies in oil, gas and petrochemical projects.

While neither of our case study firms initially envisaged entering into overseas markets, Farab was chosen as the 'National Exemplary Exporter' in 2010 by Iran's Ministry of Trade. Farab won the award along with long-established exporters in the mining, detergents and tractor manufacturing industries. Currently, Farab is the second-largest applicant for export funds to the Iran Export Development Bank. Similarly, the success of Mapna in finishing complex projects on time, occasionally even earlier than the promised schedule, in diversifying into different project markets, in exporting to regional markets and in growing into a large holding has inspired similar transformations in other project sectors of Iran, such as oil, gas and housing. This overall level of achievement was not anticipated in the import-substitution approach prevalent in the country at the time the firms were established. Instead, the firms progressively accumulated higher levels of capabilities because of their internal aspirations to expand and in response to the dynamics of external and internal forces.

The journey of LSIC started in a protected local market with no initial intention to enter into overseas markets, but LSIC gradually gained more strength, supporting each firm to succeed in competitive local markets and in overseas markets at later stages. In its early stages, LSIC progressed under the pressure of organising an increasing number of projects in order to respond to the rapidly-growing levels of electricity consumption in the country. Although the firms received inputs from leading foreign systems integrators, such as knowledge and computer applications, to build their capabilities in the early stages of LSIC evolution, the transformation processes shifted from an emphasis on overseas sources towards more reliance on the resources within the firms and in the local context at later stages.

The three core constituent parts of LSI capabilities co-evolved and fed into each other through the observed evolutionary paths. Several instances were shown in which strategic SI capabilities fed into the development of pre-project, project, post-project and functional capabilities. Strategic decisions to vertically integrate along the value chain, to transform turbine manufacturing into a mass manufacturing mode and to restructure the organisation affected the development of functional SI capabilities, as well as project, pre-project and post-project capabilities in Mapna. Similarly, the strategy to enter into new local and international markets was shown to impact the accumulation of intermediate pre-project, project and functional SI capabilities in both cases. In addition, the commitment to continuous improvement, a building block of strategic SI capabilities, fuelled the progress in the three core constituent parts of LSIC.

Looking across to other constituent parts of LSIC, the progress towards advanced levels of post-project and pre-project capabilities depended on the advancements in functional SI capabilities in understanding the technological needs of clients, preparing better proposals and acting on the feedback. Likewise, the growth in functional SI capabilities, particularly at basic innovative and intermediate innovative levels, expanded market possibilities. From a broader perspective, pre-project capabilities were important in securing new projects, the lifeblood of a project business, in order to bring in the financial resources essential to sustaining the growth of capabilities.

Despite the similarities and common patterns observed in the overall progress, LSIC proceeded along firm-specific paths, ending up at distinct levels of achievements across the three core constituent parts of LSI capabilities in each firm. In terms of our framework, Mapna was, at the time of the empirical research, behind Farab in functional SI capabilities, still progressing through the intermediate innovative functional SI stage, while Farab had already matured to an intermediate level and had embarked upon learning the advanced level. On the other hand, Farab was behind Mapna in project and strategic SI capabilities, accumulating the intermediate level of project SI capabilities, while Mapna had already matured to the intermediate level in project SI capability and has progressed further in building the intermediate level of strategic SI capability. Intriguingly, both firms expanded throughout the period of this study, even though each of them had weaknesses in one or two aspects of LSIC.

Mapna expanded rapidly over around 15 years in spite of its weaknesses in functional SI capabilities. As the evidence shows, the drag of weak functional SI capabilities on the overall performance of the firm was compensated in the local market by strong project SI capabilities and, more significantly, strong strategic SI capabilities, to control the local value chain of the industry, to create strong barriers to entry of local competitors, to convince the local client to homogenise its demands and to develop standard designs for power plants which minimised the need for functional SI capabilities in projects. However, the increase in competition, supported by the local client, and the new technological requirements of clients negatively affected the balancing power of strategic and project capabilities in Mapna. In the case of Farab, weaknesses in project SI capabilities were concealed as the local client was unable to finance faster projects and had unintentionally created a space for Farab to blame delays on dam contractors. The failures of Farab to enter into or win some overseas competitions revealed these weaknesses.

To answer, at least partially, why some of these differences and common patterns emerged, we will need to understand how LSIC proceeded at the firm level. The dynamics of LSIC evolution at the firm level can be explained within the wider context of the overall expansion and development of the firms in our study. The firms evolved towards changing goals and strategies. Within this context, LSI capabilities, considered as a system of interacting core constituent parts, co-evolved with strategies in the sense that strategies were often permitted or inspired by progress in capabilities while, on the other hand, strategies governed the accumulation of capabilities at least in the form of implying certain directions in the development of LSI capabilities.

Consistent with the framework of Hughes (1983), the evolution of LSI capability, in this context, was shaped through continuous emergence of reverse salients constraining the overall progress of the firms. As a result of the reverse salients, remedial action was required if the firm was to proceed. Resources were therefore dedicated to defining and then resolving the critical problems inherent in the reverse salients.

The emergence of reverse salients in the system of LSIC was usually sensed through some triggering factors or signals, including accidents or changes in the environment, developments inside the firm, or a complex combination thereof. When the signals appeared, managers and engineers went through a more holistic appreciation of the evolving system to identify, define and solve the critical problems inherent in the reverse salient.

As the evidence indicates, accidents and failures took place during the operation of power plants or the participation in competitions. Changes in the environment encompassed a variety of instances, such as the emergence of market opportunities, the decline in demand, the imposition of trade embargos, changes in the extent of competition in the local market and changes in the sophistication of demand. On the other hand, forces arising from inside the firm included new market and technological possibilities offered by progress in capabilities, new aspirations as a result of changes in the management or structure of the firm, and the emergence of complexities in the management of the expanding firm.

Triggering factors, however, did not operate deterministically to define critical problems. Rather, they were interpreted by managers and engineers in the light of two variables: (1) the status of LSIC inside the firm, especially strategic SI capabilities; and (2) the technological characteristics of the product. The combined effect of these variables constructed the ways in which critical problems were perceived, defined and addressed in each firm.[17]

After the critical problems were defined, remedial actions were performed through speculative transformation processes in the critical areas. These transformation processes were characterised by concentrated activities and high organisational commitment, while slow and often unsystematic progress was made in other areas of the LSIC system. This uneven progress often resulted in the emergence of new reverse salients in the face of new dynamics.

The firm-specificity of variables in this general process of the continuous emergence of reverse salients, and the following firm-specific concentrated problem-solving efforts imparted a firm-specific LSIC evolution to our case studies. In other words, the combined effects of specific

[17] Triggering factors or signals were usually conceived as opportunities, threats or restrictions, depending on the situation and the status of the firm's capabilities. The effects of the technological characteristics of the products were limited in nature as firms had the choice to change their products and related technological characteristics. Furthermore, the same technological characteristics could be interpreted distinctively by each firm.

signals appearing to each firm, differences in the times at which they happened to each firm and other circumstantial issues surrounding those signals induced firm-specific variations in paths of LSIC progress. The firm-specific status of LSI capabilities and the differences in the technological characteristics of the products affected the interpretation of these signals and the identification of critical problems. The distinctive inputs and transformation processes that were deployed to correct the perceived critical problems also affected the progress of the LSIC system. The combined effects of these factors help explain the distinctive paths followed by each firm.

As such, even if both firms faced similar signals at the same particular time, differences in the status of their LSI capabilities, especially their strategic SI capabilities, and the different possibilities offered by the technological characteristics of their products could lead to different interpretations of signals, and hence the definition of a distinctive set of critical problems in each firm. Even if exactly similar critical problems had been defined, the distinctive transformation processes adopted and the distinctive quality of inputs provided into them by each firm could further explain the differences in the outputs.[18] Even though the current and previous empirical chapters provide numerous instances of reverse salient dynamics, a few examples help clarify the point.

Facing the goal of substituting expensive international prime contractors of local hydro power plant projects at the outset, the initial status of strategic SI capabilities in Farab, particularly the background knowledge of its founders, their ambitions and values, was behind the identification of operative functional SI capabilities as a critical problem. Accordingly, organisational resources and high commitments were concentrated on that area. Later, an accidental, turbine failure in one plant, and the peculiar behaviour of the leading foreign systems integrator responsible was a signal that was interpreted in the light of progress made in the firm's capabilities, especially the developed state of confidence and the self-motivation of engineers in technical tasks. This reflection resulted in the identification of basic innovative functional SI as a new critical problem impeding the provision of reliable technical support to clients.

Throughout these periods, due to the composition of signals and the ways in which they were interpreted, project SI capabilities had not emerged as a critical problem constraining progress in Farab. Accordingly, an independent, trial-and-error approach, sometimes only carried out

[18] As the evidence shows, the choice of transformation processes and the quality of inputs provided for them depended largely on the status of LSI capabilities in each firm, and on external signals.

by motivated individuals, was followed to build this capability. However, the confluence of signals produced by the increasing competition in the (shrinking) local hydro market, the attempts of the firm to enter into overseas markets and the implications of the sophisticated demands of new clients were interpreted through the enhanced level of LSI capabilities in Farab, especially the developing strategic SI capabilities, to identify (intermediate level of) project and (intermediate and advanced innovative levels of) functional SI capabilities as new critical problems. As such, Farab concentrated on building higher levels of capabilities in these two areas simultaneously to progress in overseas competition.

However, due to the composition of signals and the ways in which they were interpreted, the lack of a higher level of strategic SI capabilities had not yet emerged as a critical problem in Farab. Slow progress has therefore been made in enhancing this capability so far.

Facing similar initial challenges and objectives to Farab, the initial status of strategic SI capabilities in Mapna, particularly the knowledge of its founders, their ambitions and values, generated a different interpretation of the situation, leading to the recognition of project SI capability as the critical problem. Later signals coming from a growing local market and the favourable policies of the Ministry of Energy were analysed through the lens of the entrepreneurial characteristics of Mapna's leaders, a part of strategic SI capability, to identify (intermediate levels of) project SI capabilities as a new critical problem constraining further progress in the local electricity market. The remedial action, in that context, was chosen to become vertically integrated across the value chain of the industry.

Later, new signals arising from the slow speed of projects compared to the market demand were interpreted in the light of the new status of LSI capabilities in Mapna and the technological possibilities offered by the product. This reflection resulted in the identification of project engineering activities as a new critical problem prolonging the projects. As such, efforts were concentrated on developing a standard firm design for power plants to reduce the duration of projects, enabling further progress in the local market. Throughout all these periods, weak functional SI capabilities did not emerge as a critical problem and Mapna proceeded by finding ways to compensate for this weakness with its stronger project and strategic SI capabilities.

Recently, the confluence of signals originating from the recurrence of technical problems in plants delivered by Mapna, the increased threats of competition in the local market and the emergence of complexities in the management of the rapidly growing firm have been analysed in the light of the current status of LSI capabilities in Mapna. As a result, (basic and intermediate levels of) functional SI capabilities and (intermediate level of) strategic SI capabilities have been defined as the critical problems that constrain progress in local and overseas markets. Mapna, in consequence, has concentrated on building higher levels of these two capabilities simultaneously.

The next chapter discusses the main empirical findings and conceptual contributions, as well as the implications of these findings and the limitations of our research.

9. Chapter Nine: Conclusion

This study began by observing the reliance of the Iranian electricity sector on local capabilities for undertaking large and complex development projects. The empirical challenge was to analyse how far these capabilities had advanced and what could be done to enhance them further. Thus, the research has focused on investigating systems integration as the core capability of firms in the business of engineering and developing large electricity generation systems, recognising this business as a case of high-value high-technology capital goods industry (sometimes referred to as CoPS in the innovation studies literature). Accordingly, the thesis has aimed to examine the depth of systems integration capability in the latecomer context, conceptualised as latecomer systems integration capability (LSIC), and to understand how it has evolved over time.

The research was carried out as an exploratory, qualitative case study, combining elements of latecomer theory, systems integration in the context of advanced countries and capability theory to develop the framework. The framework was then applied to the evidence from two major Iranian systems integrator firms leading the engineering and development of power plant projects. Evidence was gathered on the development of micro-level attributes such as people, knowledge, processes and structures underlying LSIC, along with the changes in products and outcomes of activities. These categories of evidence were combined with evidence on the internal context of the firms and the external environment to reveal the achievements in building LSIC and to understand the dynamics behind the evolution.

The thesis makes two main contributions to knowledge. Firstly, it extends the literature on latecomer capability building by investigating the nature and evolution of LSIC. It shows how the two Iranian firms entered into the business of systems integration of complex power plant projects and gradually built higher levels of LSIC, allowing them to succeed in competitive local and overseas markets and to diversify into local markets of other complex projects. Secondly, the thesis explains the complex variations observed in paths of LSIC evolution at the firm level by investigating the interaction of factors internal to the firm with changes in the external environment.

This chapter summarises the main findings and their implications for theory, research, business strategy and government policy. The chapter is organised into four sections. The first section presents the empirical findings. It includes revisiting the concepts that were provisionally defined at the early stages of the research in light of the evidence, and encompasses a brief discussion of the evolution of LSIC in Iran's electricity sector. The second section explains the contributions of this research. The third section points to the limitations of the thesis. The final part of this chapter discusses the implications of this thesis and suggests future research opportunities.

9.1 Empirical findings

9.1.1 On the nature and definition of LSIC

In this research, latecomer systems integration capability was defined as a collection of attributes that permit the latecomer systems integrator to conduct systems integration activities. LSIC was further provisionally operationalised in Chapter Five, by breaking it down into three core constituent parts. The empirical research enabled the elaboration of the nature and composition of LSIC.

The latecomer systems integrators examined in this research were established to substitute imports of systems integration services needed for the management of power plant projects in the local electricity market.[1] The firms did not initially intend to enter into overseas markets or compete at or near the technology frontier with leading foreign systems integrators. Instead, they simply hoped to meet the limited objectives of helping to serve the local market by providing low-cost project management services, while sourcing core equipment and engineering services from foreign suppliers.

These latecomer firms faced three major barriers to growth. The first barrier originated from their lack of experience in the business. The firms had no project history indicating that they were officially not qualified to participate in project bids, either in local or overseas markets. On the other hand, they had a partial understanding of the complexity of the industry value chain, and of how the dynamics of the value chain might affect the sustainability of their position.

The second barrier was in networking. A local network of suppliers for many key parts of the systems hierarchy was missing. In addition, latecomer systems integrators were disconnected from the international chain of suppliers.

The third barrier was technological in nature. The latecomers were dislocated from international sources of knowledge and innovation in systems integration, and lacking in

[1] The initial funds were drawn from state resources, but the firms were later registered as private entities.

engineering and project management capabilities. The local universities did not have resources specialised in the systems integration of power plants and (related) local science and technology systems were poorly developed. Even if parts of such a system were developed, local firms were unaware and disconnected from them at the time.

Despite these barriers, the latecomers enjoyed two sets of potential advantages or opportunities. The first opportunity was the potential of cheaper systems integration services allowed by the existence of low-cost human resources and low-cost manufacturing or contracting firms in the local market, although the contractors were often not specialised in the industry and had to be upgraded. The second opportunity was the local market. The local market was large and growing, for at least the medium-term. Regarding the demand, the clients had fairly sophisticated technological needs[2] but were willing to tolerate the risks of time and cost deviations in projects to some extent in order to support the initial growth of local systems integrators.

The local state clients significantly helped the latecomer system integrators overcome barriers to market entry. They accepted high levels of risk by ignoring the lack of project experience in the firms and giving the first projects to local firms without running competitions. This level of support was inspired not only by the prospect of lower-cost local systems integration services in the future but also by the wider commitment of policy makers to import-substitution ideas, made up of policies to increase the share of local content (i.e. components, sub-systems and contracting services) in local electricity generation projects.

Furthermore, the local clients[3] divided the aggregate demand into packages of projects which gave the latecomer systems integrators a strong position to connect with foreign suppliers and negotiate knowledge transfer agreements. These agreements included the transfer of systems integration capabilities to the firms in question, in addition to wider arrangements to help develop capabilities among a number of local contractors and manufacturers. As such, a local chain of suppliers was established over time, although this did not cover the full value chain of the projects.

LSIC in these cases are largely composed of four sets of attributes:

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[2] The clients of power generation projects in Iran employ educated and experienced human resources and monitor the progress of the product market to maximise the return of their investments. They often have sophisticated and advanced technological needs. We expect that the same trend exists in other developing countries due to the economic aspects of these projects.
[3] The local clients refer to the state client for hydro power plants (AabNiro) and the state client for thermal power plants (Sazman e Touse Bargh).

(1) Technical and strategic knowledge. Technical knowledge covers issues such as the behaviour of product systems and components, their performance, underlying technologies, materials and the range of suppliers. Strategic knowledge covers issues such as the structure and dynamics of the industry, and the dynamics of markets, suppliers and competitors. Technical and strategic knowledge could be embodied in forms such as experienced human resources, or disembodied in forms such as standards, technical specifications and reports.
(2) Procedural knowledge relates to the characteristics of tasks and ways of organising and coordinating them. This knowledge could also be embodied in people or disembodied in forms such as guidelines, processes, instructions, organisational structures, software or databases.
(3) Human qualities such as values, ambitions, self-confidence, leadership and entrepreneurship qualities[4] of people.
(4) Other forms of capital, tangible or intangible, such as hardware, software and financial capital required to undertake activities. The composition and distribution of these attributes varies among the constituent parts of LSIC. For instance, sophisticated technical knowledge was an important component of higher levels of latecomer functional SIC, while procedural knowledge and human qualities were key attributes underlying latecomer project and strategic SIC.

The evolution of a capability was the result of changes in the set of attributes underlying it. The changes could be the results of deliberate actions or the result of events and accidents such as the sudden departure of human resources for unforeseen reasons. Deliberate changes in attributes were inspired by new expectations of the relevant activity, changes in the wider strategic objectives of the firm (which could in turn be driven by changes in external forces or internal factors), or were the results of the internal dynamics of the capabilities themselves. For instance, the procedural knowledge of managing project activities has grown over time as an increasing number of projects were undertaken. Similarly, changes in the ambition and self-confidence of human resources have led to an accumulation of higher-level capabilities and the undertaking of more sophisticated activities.

Before discussing the evolution of LSIC, another aspect of the findings should be emphasised. The empirical research has enabled us to elaborate more on the definition of two of the three core constituent parts of LSIC: latecomer project SIC and latecomer strategic SIC.

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[4] These human qualities can also be called human capital (Barney, 1991). However, we prefer to use the former term to avoid confusion over the meanings and boundaries of the human capital concept.

Latecomer project SIC permits the mobilisation of internal resources and selective drawing on external firms to formulate bids/offers and to realise complex projects within agreed performance parameters. This capability also allows firms to provide services after project delivery when this features in the scope of the contract. As such, latecomer project SI capability permits the management of a wide variety of tasks, such as understanding clients' requirements, analysing the competitive situation of bids, proposal preparation, conceptual design, detailed design and engineering, procurement and manufacturing, installation and erection, testing, commissioning and operation of the final system. Rather than dealing directly with the technical essence of these tasks, latecomer project SI capability is concerned with organising, planning and controlling the technical tasks, enabling each task to relate to the other tasks of the project in realising the project's objectives. It is also concerned with coordinating high-level decisions, such as the appropriate make/buy decisions to meet the project's and firm's objectives.

Latecomer project SIC includes attributes such as procedures and structures inspired by local or international guidelines, specific techniques and computer applications. However, the accumulated firm-specific project management knowledge, including the understanding of the nature of tasks, knowledge and experience of organising project tasks, the experience of working with suppliers and the experience of different strategies of project execution are, in practice, more vital parts of this capability. Preparing bids and managing projects also required the mobilisation of other constituent parts of LSIC to better understand the clients' needs and to formulate competitive bids. As such, the performance in bids and the performance in meeting project objectives are vital if approximate indicators of the overall status of LSIC.

Latecomer strategic SIC permits firms to conceive and implement strategic choices in the face of changing internal and external situations. The strategic choices cover issues such as the firm's position in the industry value chain, the scope of technological specialisation and outsourcing, changes in technologies and products, moving into or out of markets, changes in organisational and internal processes, and envisaging changes in LSIC.

Underlying latecomer strategic SIC are strategic knowledge elements with regard to the industry and the firm's competitors, the dynamics of the value chain, markets, technologies and the firm itself. Some organisational arrangements (structures, committees, processes and channels) also constitute latecomer strategic SIC. They cover arrangements for gathering data on changes in the environment (including technology, markets and competitors), evaluating the internal situation, analysing and discussing the intelligence, visioning, deciding on future plans, committing resources to plans, and committing to undertaking continuous improvements. Probably more important in the composition of latecomer strategic SIC are the personal characteristics of managers, characteristics such as knowledge of the business, values, ambitions, self-confidence and entrepreneurial qualities.[5]

9.1.2 On the evolution of LSIC

The firms in our study were established by Iran's Ministry of Energy to substitute the expensive foreign systems integrators of power plant projects in the local electricity market. The Ministry of Energy also desired to increase the share of local manufacturers and sub-contractors in projects. In less than 20 years, the firms have fulfilled these objectives and have gone well beyond the initial expectations by entering into overseas markets and accumulating deeper and wider LSIC.

LSIC evolved from small beginnings in low-cost project management capabilities within the protected local electricity market to having a significant position across the three core constituent parts of LSIC, namely latecomer functional SIC, project SIC and strategic SIC. The development of stronger LSIC underpinned success in the competitive local and overseas markets of power plant projects at later stages, and enabled the firms to diversify into local markets for other complex projects, such as the oil and rail transport sectors.

As such, from a technological perspective, LSIC started off by permitting low-level engineering activities in projects to coordinate the interfaces between system components and to oversee the realisation of foreign designs, then shifted to permitting more sophisticated engineering tasks related to the non-core and core equipment,[6] and finally to development and research activities to improve foreign designs and to design lower-performance systems. As the firms progressed along this path, larger investments were made in higher-risk, longer-term technological activities.

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[5]As presented in this section, the underlying attributes of latecomer strategic SI capability seem to have commonalities with what Teece (2007) describes as 'microfoundations' of dynamic capabilities. Nevertheless, the concept of dynamic capabilities needs some modifications to become applicable in the context of our study because: (1) dynamic capability is a framework developed to explain the sources of sustainable competitive advantage in rapidly changing competitive environments while the latecomer systems integrators were operating in a protected local market for a considerably long time; (2) the dynamic capabilities framework is mostly relevant to the firms that have already accumulated advanced levels of capabilities, whereas latecomer research deals with how latecomer firms build capabilities in the first place; and (3) dynamic capabilities develop within an advanced technological and market environment, whereas latecomer capabilities have to be acquired from 'outside' this environment or 'system of innovation' (i.e. from within a developing country context). There are also definitional and research problems with the dynamic capability concept, which are discussed in the literature review chapter.

[6] The core equipment comprises turbines and generators in a power plant that convert the primary energy source into electricity. Non-core equipment includes a variety of systems that are required for the efficient functioning of core equipment, such as cooling systems, air conditioners and fuel storage and dispatching systems.

As LSIC grew in depth, the firms moved up in the value chain to take over engineering-intensive roles with higher value added and lower risk profiles in projects. The enhancement of LSIC also permitted the firms to reach an internationally more competitive balance of time, cost and customisations in projects. The stronger LSIC expanded the range of bids in which they could participate, opened up new market possibilities and granted the firms more sustainable competitive positions.

While the literature suggests that building technological capabilities in developing economies often corresponds to a reverse product lifecycle, the lifecycle of power plant technologies is normally long (for example, V94.2 gas turbine technology is about 20 years old), and incremental innovations in core equipment typically continue until a particular generation of technology is discontinued in plants. We find that the overall pattern of LSIC evolution in this research can broadly be explained in terms of movements within different life stages of a particular power generation system.[7] For our purposes, we divide the stages into three: (1) conception and design of the system; (2) engineering and realisation of the system through projects; and (3) operation of the delivered system. The findings show that technological capability building in Iran has progressed in a non-linear fashion, starting from the second area via understanding foreign designs, learning how to put them into use in projects and how to integrate the proven technologies of power plants supplied by leading foreign systems integrators. Through this stage, the firms grew from integrating non-core equipment to integrating and engineering core equipment. The firms then moved forward to the third stage to resolve the technical problems emerging during the operation of the systems. Finally, they went back to the first stage, allowing the local firms to conceive and implement incremental improvements in the designs supplied by foreign leading systems integrators and, at the most advanced stage, to design their own systems, albeit from 'behind' the technology frontier as defined by the amount of R&D involved in design and development (i.e. with new generations requiring intensive R&D into systems architecture, overall design, materials, key components and various performance tests).

[7] The existing explanations in the literature of CoPS in the latecomer context could not help us make sense of our evidence regarding the evolutionary paths of LSIC. For instance, we found that the evolutionary paths of LSIC in the Iranian cases do not match with an upward move in the system hierarchy of the product as suggested by Hwang (2000). The Iranian cases started by carrying out some systems integration activities at the top level simultaneously with some tasks at the lower levels relating to non-core equipment. They gradually accumulated deeper capabilities to perform certain systems integration tasks at the level of core equipment, while simultaneously undertaking more complex tasks at the top, relating to the design of the whole plant. At the final stages, the firms took up more complex tasks related to core equipment improving upon existing designs or designing core equipment from behind the technology frontier. As such, LSIC in Iran grew through a simultaneous presence across the different levels of the system hierarchy of a power plant, adding gradually to the technological depth of its position at each level.

This pathway differs from the typical Asian pathway of catching up in electronics, starting with manufacturing (assembly) and progressing in a fairly linear fashion to engineering, design from behind the frontier and finally intensive R&D (Hobday 1995; Ariffin 2000). Rather than manufacturing/assembly of a specific product, the Iranian systems integrators in the power plant industry started with limited engineering roles in projects to put the foreign systems into use and grew over time to perform more complex engineering tasks, including the technical analysis of incidents in power plants and the engineering of core equipment in projects, followed by improvement activities and design efforts from behind the frontier.

These differences may have emerged because systems integration in the power plant industry is by nature an engineering-intensive task, dealing with a variety of complex equipment that needs to be customised and engineered according to the conditions of each project. For instance, large hydro turbines need to be designed specifically for each project. Similarly, although gas turbines have standard versions, the equipment needs to be engineered in each project to reach an optimum performance. As a result, typical Asian learning strategies for mass manufacturing high volumes of exports of specific products are not applicable in this case. Furthermore, the design of complex power generation systems requires a deep technological knowledge of systems behaviour accumulated over a long time that cannot necessarily be learnt by producing higher volumes of the system or by formal knowledge transfer agreements. Rather, it requires investments in understanding the inner logic of systems through projects that allow the exchange and accumulation of tacit knowledge and skills. Complex systems tend to exhibit emerging behaviours through operation, implying that engaging with the analysis of incidents in power plants provides opportunities for learning some of the inner logic of these systems. Moving to advanced engineering and design, and R&D for new generations of power systems, among other things, depends on whether the latecomer firms strategise to compete at the technology frontier or prefer for various reasons to adopt leading designs and engage with less intensive R&D activities to improve them.[8]

The previous chapter discussed in detail the evolution of the three core constituent parts of LSIC. Broadly speaking, latecomer functional SIC grew through transferring proven designs and engineering documents from leading foreign systems integrators, with local firms focusing on understanding those designs and implementing them in projects. The capability gradually progressed to a position that allowed the firms to engineer core equipment which was

[8] Ansaldo Energia in Italy is a renowned systems integrator of thermal power plants that licenses turbines and generators, but uses its extensive base of knowledge and experience to modify the equipment and engineer the projects to achieve higher performance levels.

originally designed by foreign systems integrators. These engineering activities were performed to put the equipment into use and achieve an optimal performance in the specific conditions of each project. In addition, this level of capability permitted changes in the non-core equipment of each power plant in forms such as optimising designs, standardising designs across projects to minimise engineering efforts, and replacing materials to suit the local conditions.

Latecomer functional SIC was then gradually upgraded to permit the optimisation of plant design and incremental improvements in core equipment originally designed by leading systems integrators, and to provide sophisticated technical and troubleshooting services during the operational lifecycle of core equipment. The capability was consequently enhanced to allow design and prototypes of core equipment with lower performance levels compared to advanced designs.

Underlying this development of latecomer functional SIC are three sets of growing attributes; (a) technological knowledge about power plants and their components; (b) knowledge of design processes; and (c) knowledge of suppliers. Technological knowledge of the product grew in several areas, most notably in practical and scientific understanding of how the components work, understanding how they relate to and affect each other in the system, knowledge of emergent behaviours in plants, knowledge and experience of optimising the performance of components when they are integrated in a system, and knowledge of materials and alternative technologies. The second category was improved in areas such as explicit and tacit knowledge of the design process (for core equipment and the whole plant), manufacturing knowledge of core equipment, processes and tools for measurement and data-finding in plants, processes and tools for modelling and analysing, and knowledge of applying the experience of projects to evaluate designs. The third category arose in terms such as connecting to a wider range of specialised suppliers and R&D centres in the local and overseas context.

On the other hand, latecomer project SIC started from a mix of local and transferred methodologies for the management of single projects, but progressively moved upwards through reflecting on cross-project patterns, revising the breakdown of project tasks and related make/buy decisions, enhancing the control over the value chain, and linking projects with firms' strategies. This capability grew from conforming to a local balance of project performance factors in which one aspect often compromised other parameters, to a gradual movement towards an internationally competitive balance of time, cost and technical aspects.

Underlying this development of latecomer project SIC was the growing experience of project management resulting from carrying out an increasing number of projects in the local and overseas contexts, a better understanding of the nature of project tasks and how they relate to each other, an improved control over the time and cost of project activities, learning about external benchmarks, populating databases from previous projects, implementing more efficient forms of organization for project planning and management, establishing arrangements to gather and apply feedback from project experiences, a growing knowledge of international guidelines in project management and increasing formalisation of processes.

The evolution of latecomer strategic SIC elevated the case study firms to a situation of progressively higher capture of added value in projects, less reliance on foreign technologies and engineering services, timely moves in markets such as diversifying into overseas markets for power plant projects and local markets for other complex projects, opening up new market possibilities, and a position of implementing large-scale cross-departmental changes within the organisation.

Underlying these progresses in latecomer strategic SIC were growing and more accurate bodies of strategic knowledge on markets, industry dynamics, technologies and competitors, and increasing development and deployment of organisational arrangements for gathering strategic information, discussing and visioning as described earlier in this chapter. Equally important in this evolution were changes in the characteristics, leadership and entrepreneurial qualities of managers and engineers.

The three core constituent parts of LSIC acted as a system in the sense that they fed into each other during the evolution of LSIC and further progress in certain parts often depended on higher achievements in other parts. Additionally, under certain conditions, the weaknesses in one particular part were compensated by stronger positions in other parts. However, as discussed in the previous chapter, within the overall pattern of fast and successful catch-up, firms achieved distinct levels of depth in each of the three core constituent parts of LSIC, and differences emerged in the rate and timing of progress across the three core constituent parts of LSIC. We tried to make sense of the dynamics behind the emergence of these similarities and differences in the pathways by using a framework based on Hughes's concepts (Hughes, 1983).

In line with Hughes's framework, firm-specific recurring periods of growth, stagnation and downgrading in the core constituent parts of LSIC can be explained by the emergence of specific reverse salients and specific ways of responding to them in each firm. The evolution of LSIC, in this context, was shaped through the continuous emergence of reverse salients, constraining the overall progress of the firms. Remedial actions were therefore required if the firm was to proceed. The emergence of reverse salients was usually sensed through triggering factors or signals including accidents or changes in the environment, evolutions inside the firm, or a complex combination thereof. When the signals appeared, managers and engineers went through a more holistic appreciation of the evolving system to identify, define and solve critical problems inherent in the reverse salient.

Triggering factors, however, were interpreted by managers and engineers in the light of two variables: (1) the status of LSIC inside the firm, especially latecomer strategic SIC; and (2) the technological characteristics of the product. The interpretation of signals under the influence of these variables constructed the ways in which critical problems were perceived, defined and addressed in each firm.

After the critical problems were defined, remedial actions were performed through speculative transformation processes in the identified areas. These transformation processes were characterised by concentrated activities and high levels of organisational commitment, while slow and often unsystematic progress was made in other areas of the LSIC system. This uneven progress often resulted in the emergence of new reverse salients in the face of new dynamics.

9.2 Contributions

In addition to its empirical contributions, the thesis hopes to have made two conceptual contributions related to capability building at the firm level in developing countries. First, the thesis has combined elements from the latecomer firm literature, the literature on systems integration of CoPS in developed countries and the capability literature to define latecomer systems integration capability (LSIC) as the core technological capability of latecomer systems integrator firms, and to develop a framework for investigating its evolution. Towards this end, the thesis brough together managerial, technical and organizational perspectives in definition of LSIC.

The empirical research has helped to validate the LSIC concept by showing how Iranian systems integrators in the power plant industry have accumulated broader and more sophisticated attributes underlying LSIC, ascending the staircase of LSIC gradually, but not yet achieving its final level. As such, the firms have progressively taken over more complex technological tasks from foreign firms in projects, broadened the potential positions they could take up in the value chain of the industry, captured higher added value in projects and extended their market possibilities.

This research on the nature and evolution of LSIC contributes to latecomer theories (for example (Hobday, 1995; Hwang, 2000; Mathews, 2002; Bell, 2007) extending the breadth of its sectoral coverage as well as the conceptual literature on latecomer firms engaged in catching up. In particular, the thesis is relevant to those firms envisaging entering into systems integration of high-value high-technology capital goods (or CoPS) within a latecomer context, a subject that has not been investigated in much depth in the literature. The thesis has combined elements from the previously-mentioned bodies of literature to define and understand systems integration capability, identify the core constituent parts of LSIC and construct a staircase model as a benchmark to illustrate some levels of depth in LSIC. Furthermore, the research has added to the literature on capability (such as Levinthal and Myatt 1994; Helfat and Peteraf 2003; Augier and Teece 2006; Teece 2007) by showing how to operationalise research on the evolution of micro-level attributes underlying LSIC, framed in the changing internal context of the firm and its changing external environment.

By developing the LSIC concept, the thesis hopes to provide definitions and frameworks suggesting how latecomer firms might consider entering into the business of systems integration in CoPS, and how they might consider enabling catch up and success in local and international competitive markets by leveraging local market opportunities. This thesis has shown that the catch-up in the Iranian context occurred via interacting with leading foreign systems integrators, relating to foreign specialised suppliers, linking with a range of players in the local context, and undertaking innovative technological activities in the latecomer context. Some elements of this research can also be used as tools by policy makers hoping to assess the development of firms through a systems integration lens, and assist them to think about effective policies in this area.

The second contribution of this thesis is in helping to understand the firm-specific variations in the evolutionary paths of LSIC. The latecomer literature in the main does not deal directly with these variations at the intra-firm level, and builds upon commonalities and approximations. To this end, as discussed above, the thesis has borrowed and adapted elements from research on the evolution of large technical systems, in particular Hughes (1983), to develop a framework for understanding these variations. This framework extends the literature on the firm-level dynamics of latecomer capabilities (such as Lall 1992;

Figueiredo 2003), proposing some mechanisms through which managerial interpretations of contextual forces (changes in the environment) and factors internal to the firm create an evolving firm-specific focus in capability building. As explained in the concluding paragraphs of the previous section, the managerial interpretations of (internal and external) triggering factors have shaped the ways in which critical problems, inherent in reverse salients of the LSIC system, were defined and addressed. The interpretations, however, were affected by the status of LSIC in the firm, especially the status of latecomer strategic SI capability, and by the technological characteristics of the product. The concentrated remedial actions following the definition of critical problems led to swift progress in the identified areas, while slow, often unsystematic developments occurred in the remaining areas of LSIC. This uneven progress in the system of LSIC often resulted in the emergence of new reverse salients over the course of time.

9.3 Limitations

Before drawing lessons from this thesis and suggesting future research opportunities, it is important to recognise the limitations of this research. Firstly, this study was carried out in the context of systems integration of large power plant projects, which are made up of some complex product systems among which core equipment comprises a large share of the project costs. The findings of this research may not be directly relevant to other sub-sectors of power generation, such as solar and wind power, let alone other CoPS industries where technological characteristics might differ significantly, for instance where a lower volume of engineering tasks is required to deliver each project, or where software comprises a larger share of project costs.

Secondly, LSIC was studied in Iran, and the context in which import-substitution attitudes were prevalent before the 1979 Revolution and were enhanced by the fear of broader trade embargos following the Revolution. In addition, the country experienced large annual investments in its electricity generation capacity for over a decade,[9] and the case study firms enjoyed a special relationship with their local clients due to common ownership by Iran's Ministry of Energy. Thirdly, the research has focused on LSIC as the core feature of latecomer systems integrators, while other firm attributes such as management of financial resources, human resources management and organisational culture were excluded from its scope. Similarly, the research did not aim to systematically examine the relationship between LSIC and a firm's performance. Finally, the common limitations of exploratory case studies

[9] Iran had the second-largest annual investment in new electricity generation capacity in 2009, after China (IEA, 2010).

should be considered before any generalisation of the findings is undertaken. The main purpose of exploratory case studies is to help develop theories and concepts and to delve deeply into the subject matter to generate indicative findings to support further research propositions. The ways to address these limitations are discussed in the next section.

9.4 Implications of the findings

9.4.1 Theoretical and empirical implications

A theoretical implication of this research is that the literature on latecomer firm theories should be extended to embrace new categories of latecomers engaged in the business of systems integration of high-value, high-technology capital goods. These latecomer firms, latecomer systems integrators to be precise, are not purely manufacturing entities, might face a different set of advantages and disadvantages compared to other latecomers in the literature, and might not necessarily intend to compete in international markets from the outset. Section 2.1 of this chapter highlights some of their distinguishing features. Future work can focus on theorising market entry strategies of latecomer systems integrators, how they build advantages in international competition and their challenges in possible transit from latecomer to leadership positions.

Another theoretical implication is that capability theory needs more precision and extension in the LSIC area. More conceptual and theoretical attention should be paid to connecting LSIC with the literature on strategy to enrich our understanding of how LSIC affects a firm's performance and creates sustainable advantages. Furthermore, the empirical research on the evolution of LSIC in diversified latecomer systems integrators hopefully shows how LSIC can build a basis for diversification.

More conceptual and empirical research is required to understand LSIC in more depth. Compared with other latecomer technological capabilities in the literature (for example the dichotomy of process and product innovation capabilities, technological capabilities, and industrialisation capabilities), LSIC appears to have a more complex structure of interacting technological and non-technological parts, in which non-technological parts play a major role in shaping the overall evolution of LSIC.

Furthermore, as noted above, the evolutionary paths of LSIC might not follow the 'typical' reverse product lifecycle patterns found in the case of Asian electronics exports. While the latecomer literature tends to investigate the pathways of technological catch up in a specific product, latecomer systems integrators might progress through occupying different positions in the value chain of their industry and move from taking technologically simpler roles in projects towards sophisticated engineering and design activities related to the core components. In the case of Iran, the latecomer systems integrators relied on their local markets for growth. This research hopes to have provided a helpful starting point for examining the progress of LSIC in other sectors and in other developing economies.

More empirical research is required in other CoPS industries and within the context of other developing countries to find out whether the overall progress of LSIC observed in this research was unusual or forms part of a broader pattern across CoPS industries in developing countries. Indeed, research on the successful Asian economies shows that fast growing developing country firms normally focus on 'simpler' mass produced goods exports for the purposes of catching up, rather than technologically sophisticated capital goods. However, it could well be that in the more advanced emerging economies (such as China and India) there are also opportunities for high-value, high-technology capital goods (CoPS) entry. Furthermore, future empirical research on firm-specific variations in the paths of catch up in technological capabilities, in the context of other developing countries and across other latecomer industries, can reveal whether the dynamics identified in this research are specific to latecomer systems integrators of power plant systems, or more common across CoPS or even wider afield. In these empirical works, special attention should be paid to differences in the technological characteristics of the products.

Finally, our research has shown that the Iranian firms have not yet reached the final levels of LSIC, let alone embarking on a transition to leadership. Future empirical research could focus on success and failure cases of transition from latecomer to leadership in CoPS systems integration, explaining the reasons for these patterns. There are already a few cases, such as the Brazilian firm Embraer in the aircraft industry, that seem to be approaching the technology frontier in some areas, and more cases might emerge in the future. This type of firm-level research, incorporating particular aspects of the national context, would help us understand the challenges of transition and draw managerial and policy implications.

9.4.2 Implications for management and policy

Regarding business strategy, although both cases have revealed distinctive pathways and levels of achievement in building LSIC, a number of managerial suggestions follow for both firms concerning the further development of LSIC. Firstly, management teams need to continue and, if possible, deepen the trust and support for the firms' engineers and technical staff to undertake technological activities. This support, up to the time of writing, has probably been the most important input into the transformation processes of LSIC. Secondly, both firms should consider increasing their financial investment in research and engineering activities, and wherever possible enhance their connections with elements of the national system of innovation. The Iranian government has recently adopted aggressive policies to enhance the research base of the country, including a threefold increase in the annual research budget for the next five years (The Fifth Comprehensive Development Plan). This opportunity can be taken by both firms to help share the costs of creating the laboratories and research centres required for further design and engineering activities for improved or new generations of core equipment of power plants. Thirdly, both firms need to further increase their knowledge of and intensify their interactions with global technological advancements and alternative technology suppliers, through channels such as active presence at conferences and exhibitions, linking with research centres and, if possible, interacting in development projects with leading foreign systems integrators. Fourthly, the senior management teams of both firms could initiate improvements in the current level of project performance by setting challenging performance goals and by investing in streamlining the interactions among the different organisational units involved in the projects.

As well as the common points above, specific suggestions follow for each firm. Farab designed and tested a large turbine with high energy conversion performance. Further development at this stage will require undertaking more design projects and enhancing the scientific base of the company. Farab could leverage its design experience and convince the local client to order small hydro turbines, which often have lower levels of performance but need to go through the same design process. This could create a platform for Farab to enhance its design capabilities and gradually convince the local client to order larger hydro turbines. Regarding Mapna, the firm could engage more extensively with the technical problems emerging in the operation of power plants in order to enhance its basic functional SI capability, which, as we have seen, presents a bottleneck for further LSIC development.

In terms of policy implications, the government could support the firms to upgrade their LSIC through several measures. Policy makers could consider mobilising additional government resources and further encouraging national financial institutions to support the presence of Iranian firms in overseas markets. The progress of firms in overseas markets would not only diversify their income sources but could also generate a plethora of learning opportunities. Specifically, thermal and large hydro power plants are high-cost infrastructure projects and are often financed or insured by foreign sources in developing countries.[10] As the evidence shows, governments of economically advanced countries support exports of their firms to these regions by affecting the terms and conditions of 'official export financing' mechanisms such as Export Credit Agencies, development assistance funds and other forms of bilateral or multilateral aid (Evans and Oye 2001; Grunbacher 2001). For instance, Export Credit Agencies often provide services for a project on the condition that at least a certain share of the products and services in the project is sourced from firms in their home country. The data gathered during the fieldwork indicates that related financial organisations in Iran have far less experience in supporting large complex projects. Offering particular policies in this area, however, requires in-depth knowledge of the subject and a thorough investigation of the current situation in Iran, which needs additional efforts beyond the scope of this thesis.[11]

Another suggestion is for the government to encourage state clients in other complex project markets, such as the oil and gas markets, to interact more extensively with these firms. In particular, this dimension of policy could explore the opportunities of using local LSIC for designing and manufacturing similar complex equipment in the local oil and gas markets.[12] In addition to diversifying the income sources and creating learning opportunities, this policy would help the firms broaden their technological base and perhaps create a justification for further technological developments. However, this possibility requires very careful evaluation as it could be unwise for any company to go beyond its core, distinctive LSIC.

More specifically in terms of latecomer functional SIC, policies could support the efforts of our case study firms in building design capabilities for core equipment. The current ownership structure of the electricity industry in Iran provides an opportunity for this purpose. The state companies own and operate large hydro power plants in the country. The government could therefore encourage them to source more spare parts of hydro turbines from Farab. Although the clients are reluctant to order designs of the main hydro turbines of a plant locally, they are probably less opposed to the idea of ordering the complex spare parts, such as blades for the existing large turbines, from Farab. The government could also support the designing and testing of large sample turbines instead of financing expensive large hydro

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[10] As Chapter Three shows, developing countries experience high growth of electricity consumption, representing a large market for power plant projects in the future.
[11] Evans and Oye (2001) assert that national Export Credit Agencies compete with each other to offer better terms for financing exports, and explain how their activities are partly regulated through agreements. The report reads: "Energy projects make up a major part of ECA [Export Credit Agencies] portfolios and are a battle ground in the fierce competition for equipment and engineering orders" (p25). They show the differences between Germany, the United States and Japan in using government resources for supporting their respective national firms in winning project contracts in developing and emerging countries. Grunbacher (2001) presents historical data on how the German government directly provided loans and other forms of support to their nascent firms for exporting to developing and Eastern European countries in the 1950s.
[12] For instance, smaller gas turbines are used in gas transmission projects.

plants, thereby creating a platform to exercise and enhance design capabilities in Farab. Alternatively, the state could support local firms in financing smaller power plants to use core equipment designed locally. Finally, the government could encourage the upgrading of LSIC by defining challenging systems integration tasks in projects financed by state resources, thereby stretching the firms to the limits of their capabilities. These challenging goals could include shorter project times and needs for different (and more complex) equipment. These suggestions are justifiable considering the major role of Iran's government in financing new power generation projects and the evidence this thesis has provided about its defendable record in initiating and supporting the growth of latecomer systems integrators so far (for example see section 2.1 of this chapter).

Firms in other complex project sectors of Iran, or similar firms in other developing countries, at least in the same industry, that wish to enter into systems integration of CoPS or which have already started the journey but not progressed as far as the firms in this research, can draw encouragement from this thesis. Latecomer systems integrators in most CoPS industries face two interrelated sets of complexity: complex technological activities, and a complex industry value chain. Our cases show that building knowledge of the industry has been a major factor behind the creation of sustainable advantages. While both firms had a partial understanding of the industry at the outset, they gradually learned about it through internal efforts and through experiencing successes and failures in the market. Other firms, either in Iran or in other developing countries, can equip themselves with this knowledge more quickly than our case study firms by hiring in experienced individuals from similar local firms or foreign systems integrators. This strategy will hopefully speed up and improve the catch up process.

Our cases have shown that positions based on low-cost project management are exposed to threats of new low-cost competitors. Accordingly, enhancing technological capabilities should be recognised as a priority in latecomer systems integrators from the early days, in parallel with investments in learning project management. This can start with low-cost engineering activities under foreign supervision and small investments in the technological understanding of the product systems the firm delivers. Although latecomer systems integrators can start their lives without strong linkages to local sources of knowledge, personnel and technology, progress from certain stages onward may require such interactions. Local firms in Iran or in other developing countries may unexpectedly find some specialised suppliers and related technology sources within the local context, as did Farab and Mapna, for designing turbines and modelling the behaviour of product systems.

Although the Iranian government supported the development of LSIC in our case studies, the research shows that the internal aspirations of firms in terms of growth and their commitment to continuous improvement are perhaps more significant factors during the progress, and are often led by 'visionary' and skilled individuals in senior positions. We would expect, therefore, that the progress of other latecomer systems integrators in other contexts and other nations would depend, at least to some extent, on the leadership abilities and characteristics of such key individuals. As such, policy should take account of the human resource base with respect to the leaders of the industry.

The evidence suggests that latecomers in this industry, and perhaps in most other CoPS, can confront a vicious cycle preventing them from developing LSIC. Considering the natural tendency of clients in this industry to be conservative in the choice of systems integrators, the lack of experience in latecomer firms can prevent them from active participation in projects or from undertaking technical changes in projects and complex systems. This pattern sets stringent limits on the accumulation of the experience that is needed to improve the reputation of latecomers, creating a vicious cycle. Supportive clients, most likely to be found in the local market, might be one way of breaking this cycle by tolerating the initial risks.

In terms of policy implications, as clients in foriegn markets might be reluctant to commit to long-term investments in creating local technological capabilities, the existence of forward-thinking and willing local clients, and an appropriate size of local demand may be a necessary but insufficient condition for initial growth to occur. It would therefore seem very challenging to establish a systems integrator of power plants in a developing country with a small local market or with unwilling clients, although the experience of small European nations, such as Finland and Sweden, shows that export orientation can help overcome small market disadvantages. Even so, the challenge for lower-technology catching up nations is far more daunting than the case of European nations. If the industry does begin to take off, the protection may be lifted over time to allow further progress in capability building, as exposing firms to competition in the local market or in export markets can be a powerful stimulus for learning higher levels of LSIC.

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