Inter-domain translational research on planning and scheduling: operating rooms vs. job shops

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Abstract: On the surface, it would appear relatively easy to translate most analytical and modelling results from the Industrial Engineering research on job shop scheduling to other contexts such as operating rooms in healthcare. In this paper, we will discuss translational research between the job shop and operating room scenarios and describe the role of field research in determining the gap between two domains. We conclude that further field-based research is required on operating rooms to better understand the sources of uncertainty, and the dynamic relationships that exist within the process.

Keywords: translational research; operating rooms; planning and scheduling; job shops.

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Biographical notes: Kenneth N. McKay has spent over 25 years exploring the dynamic nature of job shop scheduling using interdisciplinary methods. The results of the field research have informed the formulation of production control heuristics which attempt to capture some of the key decision making processes observed in real factories. A secondary research thrust is analysing the history of production management and the development of an evolutionary model of factory control. His current research agenda is focused on surgical suites and emergency departments – using a variety of field methods to understand the sources of uncertainty and variance.

1 Introduction

Translational research or translational science traces its roots back to approximately 1968 and the bench to bedside discussions that focused on research – practice gaps occurring in the medical community (Feldman, 2008). Operations management had its equivalent discussions starting in the early 1960s about the gap between theory and practice (e.g., Pounds, 1963). Over time, the bench to bedside terminology has evolved into translational research, and this term has been widely used since the early 2000s (Liang, 2003). In Operations Management, the same benefits of translating theory to practice were well stated by Fisher (2007) using examples from vehicle routing, automotive assembly plants, maintenance monitoring, quality, demand planning, forecasting and supply chains. In this paper, Fisher discusses how case studies and empirical data collection have been used to inform theory building and for theory validation. There is no mention of advanced field methods such as ethnographic studies or using techniques from socio-technical literature, nor the direct application of methods from psychology or sociology to study the details of decision making. While there are a number of successes in various topics as noted by Fisher, the same degree of success of applying translational research has not been attained in the area of dynamic job shop scheduling. There has only been limited success in having empirical work inform theory building (e.g., McKay, 1987, 1992), a few successes in using empirical methods to validate theories (e.g., Higgins, 1999; Crawford, 2000), and very little success in having the mathematical models and methods from research used in day to day operations in job shops (Wiers, 1997). In addition, where there have been successes, the empirical work has usually used a combination of case studies, data collection, and various methods from ethnographics, socio-technology, sociology, and psychology, not just case studies and data collection (McKay, 1987, 1992; Wiers, 1997; Higgins, 1999; Crawford, 2000, and various examples in Fransoo et al., 2011). There has been some limited success in areas such as nurse scheduling using algorithms and heuristics, but the actual translation from academic to usage was not strong (Kellogg and Walczak, 2007).

At the same time, researchers are applying Operations Management concepts from manufacturing and services to the healthcare situation. For example, Gupta (2007) adapts capacity allocation methodology, Olivares et al. (2008) use the newsvendor model to provide guidance for reserving times for individual cases, and Blake and Donald (2002) use integer programming for block scheduling. As Gupta carefully explains, there are many assumptions made and challenges when it comes to the numerical distributions used and simplifying constraints – many of which are not thoroughly understood and are open for future research. While some of this research is capacity oriented (e.g., Gupta, 2007), we are interested in the operational level of detailed scheduling and sequencing: the analytical models for planning and scheduling, factors included in the models, predictive and reactive scheduling of resources, and rescheduling issues.

There are two common forms of operating room scheduling: one using blocks of time, and one attempting detailed sequencing. Examples of block scheduling research are Blake and Donald (2002), Ozkarahan (2000), and van Oostrum et al. (2008). In the area of detailed scheduling and sequencing, the shortest processing time heuristic has been investigated by Lebowitz (2003a), earliest and latest start time by Dexter and Traub (2002), and an example of research that combines both block and detailed sequencing is Jebali et al. (2006). Denton et al. (2007) look specifically at sequencing decisions under uncertainty and use field data as part of their experimentation. They also have an excellent discussion of their assumptions and the differences between research and the real world situation. An example of taking the classical formulation from Industrial Engineering and extending it to capture some of the operating room situation is that of Pham and Klinkert (2008). Pham and Klinkert extend the classic job shop scheduling formulation to include some of the operating room characteristics such as the lack of buffers, and also provide an excellent discussion on limitations and future research. For a comprehensive review of planning and scheduling of operating rooms, Cardoen et al. (2010) is recommended. These researchers report an extensive review and categorisation effort that includes patient characteristics, performance measures, decision delineation, research methodology, uncertainty and applicability of research. They note that few efforts take a comprehensive view of the situation including pre- and post constraints, that most of the research deals with elective surgery, and that there are many issues with terminology and unclear definitions. It is interesting to note that field methodologies beyond case studies and empirical data collection are not discussed in the review.

In this paper, we will review and analyse the challenges that arise when considering inter-domain translational research for models and methods that strive to be realistic and rich in their modelling fidelity: models and methods that strive for results beyond theoretical bounds. Specifically we are interested in models that attempt to address two of the gaps identified by Cardoen et al. – holistic views of the situation, and greater scope than just elective surgery, which introduces a high level of uncertainty. We will specifically discuss the role that advanced field methods play in the translational process of understanding what is the same and what is different; providing some insights for how the field research can be performed and structured.

2 Classical operations management to healthcare

Translational research is now being used to describe how models and methods from one domain are being used in another, and Pham and Klinkert's work is an example of this, taking a general job-shop scheduling formulation and extending it to the operating room. In theory, there are great opportunities for this type of research and application, as there are many decades of research to draw upon. It is attractive as one does not have to start from scratch, and in general the whole healthcare situation seems a suitable domain. Inter-domain translational research has the potential to bear solid results in healthcare situations such as operating rooms, ambulance movement, material control, emergency rooms, and so forth. For over a century, Industrial Engineering has studied, debated, discussed, and contemplated many manufacturing situations that have a number of characteristics seemingly similar to those found in different health care scenarios. In many of the situations, researchers and practitioners in manufacturing have produced results with varying degrees of success and application, as noted above (e.g., Fisher, 2007). However, to understand whether the results from one domain have potential to be applicable to another domain, it is necessary to understand the essence or Zen (all that makes it what it is) of both situations, and to determine what is indeed the same and what is different.

In pure theoretical work that can help understand and guide the boundary conditions, it is relatively easy to identify the key variables and assumptions from the manufacturing abstraction and determine if the same variables, constraints, and assumptions exist in the healthcare abstraction. Theoretical boundary analysis using simplified models has been a major part of the academic agenda for the past half century. It is useful in almost all cases to know the theoretical capacity requirements and production profile. This research establishes a reference point that can be used to track expected improvements, or to understand how far from ideal the situation really is. Since the models are simplified, it is very likely that many of the same methods and models can be applied to the healthcare problem. The challenge with simplified manufacturing models in the past has been the ability to convert the academic model or methodology into something useful that factories can actually apply. Depending on how far removed the simplified model is from reality, some of the results have the potential for field usage. For example, in a highly automated manufacturing situation with low variance (timing, quality, setup, movement), and which also has stable forecasts, many of the highly simplified academic results on planning and scheduling can be contemplated and potentially applied. In situations like delivery and distribution which typically have richer models compared to planning and scheduling and which take into account information about traffic, routes, time of day congestion, the models and methods might be very practical to consider with little translation work required.

3 Job shop and operating room research

In many ways, the job shop and operating room are similar. The similarities that can be gleaned from the literature are:

- operating rooms often have functional specialities – e.g., cardiac
- patients coming to the operating room have some form of processing requirement – e.g., heart surgery, knee replacement
- there may or may not be a queue of patients waiting for a specific operating room type – e.g., there is a mix of demand that affects resource usage
- there may or may not be secondary resource constraints that block or starve the key functional resource (e.g., diagnostic tests such as MRI, or beds in the recovery area can block an operating room from being used) – although not present in single machine job shop research, research involving different routines and multiple machines is somewhat similar
- operating rooms are not aligned in an assembly style with the patient visiting one operating room after another – they exist as independent units where resources are moved to the patient if necessary
- the operating room area has multiple fan-ins and fan-outs
- the operating room has setup, processing and teardown stages where the room is prepped, used, and then cleaned; and where each stage potentially requires a different crew or skill set
- processing times might be resource dependent and based on training and skill of the crew – e.g., different physicians have different processing times
- some materials in inventory might have a best before date, or once opened have a limited shelf life, or might have a one-shot application that cannot be shared across processes
- some tooling might have to be specially prepped, and the preparation has a limited time window for usage
- yield and output quality might be resource dependent and based on training and skill of the crew – e.g., different physicians have different success rates
- each stage has a set of tasks and an estimated processing time for each based on an initial diagnostic or requirement
- operating rooms can have resource failure, repair times, and maintenance schedules.

These characteristics certainly sound like a job shop situation. However, these are not the only characteristics that can be observed in the operating room situation:

1 arrival patterns are hard to forecast and are based on things breaking

2 types of inventory that can be kept on hand are very specialised and limited

3 processing time variance – estimated vs. actual – is extremely large as it is often impossible to know what will be done until the item is cracked open and inspected

4 due the very nature of something being broken or opened up, there is a chance that any work will result in more breakage and more repairs being needed – e.g., an injury to other organs can occur during a laparoscopic adrenalectomy (e.g., Sage, 2004)

5 the workers are specialised in process and fundamental skills and need to know how to create solutions which do not exist as standard procedures with precise step-by-step guidelines – almost every 'fix' is different from a previous 'similar' fix

6 work might not be started unless there is a certain minimum time left in the shift (this can occur in publicly funded hospitals in elective surgery situations where the surgery is rescheduled and the operating rooms are not running 24×7)

7 work may directly affect human life

8 buffers do not really exist in the classical sense

9 processing times and processing tasks may depend on pre-existing conditions, some of which have been diagnosed or arisen after the initial booking and pre-op analysis

10 certain characteristics about one patient may impact future patients being processed by the same resources (e.g., exhausting the supply of a blood type or rare medication).

These additional characteristics make it difficult to translate general job shop scheduling research to that of the operating room without doing some form of extension as illustrated by Pham and Klinklert (2008). Care and caution is probably warranted when using assumptions from the general job shop literature, and in interpretation of results. However, it is possible to consider a subset of the general job shop problem: repair shops.

The repair type of job shop is more process oriented (not product), and has the goal of fixing or healing whatever comes in the door. There might be general trends in demand (more repairs at the start of the drilling season), or predictable indicators (a mine is re-opening). These are similar to well-established expectations in certain healthcare situations, as when skiing season starts, or when a major event will take place (like demonstrations associated with meetings of world leaders). A repair shop might have some demand that is routine, not critical, and can be scheduled in – the machine is working, but it should be looked at in the next few months. This is like elective surgery. A repair shop might have priority or unexpected demand turn up when a critical fixture, tool, or machine fails and the failure is causing a major problem for the client. This is similar to an emergency surgery.

There is a great variety of repair shops and processes. In some industries, it is possible to do repairs with few setup constraints and requirements, but there are other cases when many activities must be done and resources gathered before the repair can start. In some industries, it is possible to start a repair and set it aside to do another, or to continue the repair the next day, but there are other cases that when you start the repair, you cannot stop and you must be willing to work 24 h a day to do it; or you do not start the operation unless there is sufficient time left in the shift. So, while operating rooms might appear to be job shops, they are not like the general job shop, and even within the repair job shop sub-group, there is a further refinement before the problem spaces are really similar.

It is almost possible to make a one-to-one match between operating rooms and a certain class of repair job shops. The one obvious exception is the direct link to life – but, there might still be concerns since the repair shop might be working on something that will eventually be related to human health, such as key airplane components. There might not be too many of these repair shops, but they do exist (e.g., McKay, 1987). While the repair job shop might be close to an operating room scenario based on the above points, operating rooms have two more characteristics that challenge mathematical modelling: strong constraints imposed by the culture, and politics often associated with individuals involved. While these last two characteristics might be assumed away in theoretical boundary research, they are difficult to ignore in practice or when translating theoretical results to an applied setting. There are of course cultures and politics in manufacturing, but it is rare to see the influence of these characteristics as strong as it is in healthcare.

With a few reservations related to the possible impact on human life, and to the political and cultural aspects, it might be reasonable to suggest that repair shops with a certain manufacturing profile are a starting point for considering translational research that might bear applied benefits. General job shop research concepts and methods can be applied at the high level to gain overall insights, but it is doubtful if the more specific job shop scheduling results will be of applied use; the problem space is a subset of a subset of the job shop problem. Unfortunately, repair shops have not been extensively studied or modelled. Large repair situations have drawn some attention, but there might be few, if any, research efforts which have focused on the smaller repair shop situations that resemble operating rooms, and there are good reasons for this. These shops are usually outside of the main supply chain flow, are operated by third parties, and are smaller business concerns. They are also not part of the direct, added-value flow. Nor are they involved in making new products or new processes. To put it bluntly, they are not terribly interesting to research compared to wafer-fabrication, electronics, or automotive assembly. They are not normally considered a large industrial sector, and do not have a large voice when it comes to lobbying government or gaining public attention. It is also not a sector targeted by governments for strategic grants. It is not worthy. In healthcare, the ‘repair shop’ has a reverse situation, as the operating rooms are key resources, have a high cost, are bottlenecks for the overall service and have serious inefficiencies (Gupta, 2007). Healthcare research is fundable, is an interesting topic for researchers, and has high, potential impact on society. It is worthy.

To summarise, we have the operating room situation with some research activity based on the general job shop scheduling results (e.g., Pham and Klinkert, 2008; Dexter and Traub, 2002), and very little based on the closest equivalence – a subset of repair shops. The small repair shop has been studied to a limited extent (e.g., McKay, 1987), but there is relatively little known about them. While the research community could commence on repair shop research, it is probably too little and too late to assist with the healthcare equivalent. So, we are forced to consider translating the general job shop research and this can be seen in the literature. It is not clear if any of the literature reviewed by Cardoen et al. (2010) leverages any insights about repair shops, or field driven research on job shops (beyond simple case studies and data collection). The concept of a repair shop analogy is not mentioned in their review paper.

The gap between theoretical and applied research on job shops has been often commented upon, and it is possible that a similar gap will exist between theoretical research on operating rooms and the real situation. While there may be a number of different ways to address the latter gap, one potential way is to use methods from production research on the manufacturing theory-practice gap and see if they help to understand the health care situation and assist with translating research results and methods. These methods have helped understand the differences between job shops and flow shops, and the differences between theoretical research models and the practical situation. The next section discusses how the methods used to understand the sources of uncertainty and dynamic relationships in factories can be applied to the operating room situation.

4 Field methodology

How does one go about doing appropriate field research that will provide insights and inform mathematically oriented research? Is it enough to simply go out to a factory and gather up the forecasts, routings, processing requirements, and shop floor execution data pertaining to failures, repair times, processing times, and yield? Or, go to an operating room situation and gather similar data? Is it enough to simply go out into a field situation for a few hours or a few days and watch them? Ask them what they do and why they do it? Is it enough to ask the scheduler to come to the lab and try a few sample problems you have constructed? The answer to these questions depends on your intent and expectations, and each method is valid in a certain context. I have used most of these methods at one point or another in a number of research activities and have obtained value from them. The underlying assumption is that you know what you are actually collecting, what it means, and what you can do with it. Furthermore, you need to know what you are not collecting, what this means, and what constraints this might place on your discussion and conclusion.

These methods generally provide a broad understanding of the situation and I have used these to guide further research activities at many field sites. Bowker and Star (2000) and Browne and Keeley (2004) provide guidance as to how to ask questions and how to categorise data collected. These methods are my first tier of field tools and ones that I use to gain preliminary knowledge. They have been insufficient as sole methods for understanding the deeper relationships and dynamics found in real factories. Specifically, they have been insufficient for making general statements or claims ‘with confidence’ about what information might or might not be useful in realistic modelling, or about what heuristics might or might not make sense to pursue. To take the research deeper, additional tools and methods that complement the first tier must be brought to bear.

This second tier of research methods are centred about short case studies and involve more structured interviews, or specific probes. This tier provides valuable insights and data related to certain aspects not seen or captured via the first tier. Ideally, multiple ‘similar’ case studies can be performed so that inter and intra analysis can be performed.

The third tier of research methods are used when deep, intimate understanding is desired and methods from ethnographic research are used to facilitate longitudinal field studies which provide many sample points and the ability to track events and decisions across time. Longitudinal studies also allow for methods such as Action Science (e.g., Argyris et al., 1985) to be utilised. In Action Science, a planned intervention based on a causal, theoretical model is executed and the results observed and analysed. In a production control context, this might include such actions as changing the task structure between dispatchers and schedulers, altering information flows between departments, and increasing the type and depth of information used in decision making. Care must be taken when using Action Science/Research methods to address possible bias (e.g., Cunningham, 1997). Various methods to address bias are: ensuring that positive and negative information are consciously included and discussed, having a detailed description of the situation before the intervention, having pre-measures and pre-objectives established with situational and theoretical experts before the intervention is performed, post-reviews with the situational experts for fidelity and accuracy checks, and cross validation with someone from outside of the situation. It is also important to be conservative and make careful claims of any generalisation or causal relationships – not over stepping the strength of the method.

The fourth tier of research methods are context text specific and relate to the topic being researched. For example, if the research has as a goal the understanding of how a human scheduler actually schedules, methods from Cognitive Psychology are suitable for consideration. If the goal is to understand the relationships between the scheduling department and other departments, methods from Sociology are candidates.

The four tiers have been used on the production control problem in factories, and have yielded the insights noted in the previous two sections. While not necessary for boundary-oriented research, the insights have been invaluable for researching extended models and concepts that attempt to capture more of the applied setting (McKay and Black, 2006).

The following subsections provide short literature reviews of relevant sources for tier two, tier three and tier four research.

5 Second tier: case studies

The case study method has been a popular approach for empirical work and has been used in the field of operations management with some degree of success (Meredith, 1998; Stuart et al., 2002; van Wezel and Riezebos, 2011; Berglund et al., 2011). To illustrate the popularity of the general approach, the seminal works of Eisenhardt (1989) and Yin (1989) have over 10,000 and 30,000 citations respectively. There are also many texts and guidelines for how to conduct a case study. Case studies can be used for simple discovery (e.g., McKay, 1987) that will help with theory building, or they can be used for theory validation (e.g., Crawford, 2000). In the case of theory validation, additional methods must be used to perform the actual field work to ensure appropriate rigour and quality results. Crawford (2000) used a number of complementary methods from sociology and psychology in conducting research on schedulers. In this fashion, Crawford was able to provide reasonable support for a number of hypotheses about the information flows around the scheduler and the scheduler's contribution to decision making using what are considered strong methods, which also replicated and supported previous insights gained during discovery style case studies which used weak methods (McKay, 1987). Crawford's work was non-trivial and required substantial effort on both the field side and later analysis. It was a great deal of work requiring interdisciplinary training, which Crawford has. Other case study work using complementary methodologies can be seen in van Wezel and Riezebos (2011) and Berglund et al. (2011). van Wezel and Riezebos used knowledge extraction tools in a study involving 27 planners performing train scheduling in The Netherlands, and then used detailed task analysis (observation techniques, thinking aloud protocol analysis, probing of decisions) with two planners. They used this combined knowledge base to create a prototype scheduling system that matched the task structure of the schedulers. Berglund et al. used a more traditional case study method for the data collection and observation task, and did a series of in-depth case studies on four different businesses in Sweden. However, they extended the data analysis methodology to probe the knowledge networks and contributions made by the scheduler to the organisation and process. They found that the schedulers did far more than simple sequencing, did a great deal of problem solving, and that the schedulers' contributions extended to sales and marketing as well. The level of effort and types of skills necessary to use multi-disciplinary methods in an interdisciplinary research agenda also helps explain why case study methods seem to have general acceptance for simple discovery and theory building purposes in preliminary and exploratory research agendas. The use and acceptance of case study methods for validation remains a topic of controversy (Kohlbacher, 2006; Bennett and Elman, 2006).

The case study literature provides guidelines for the number of case studies needed for different levels of claims and the literature also provides guidance for how to pick suitable case study sites (e.g., Eisenhardt, 1989). In the early stages of a translational research agenda, it is probably wise to restrict the objectives of case study research to simple discovery and perhaps theory building. Dooley (2002) and Pahre (2005) discuss the theoretical and applied issues related to theory building via case studies. To avoid overstating the case, it is perhaps best to start off by using case studies to understand the general situation, and to use them to decompose the larger situation into potential patterns and connections suitable for further analysis and research. For example, the discovery style case studies used in McKay (1987) led to a two stage adaptive control theory modelling how schedulers view their problem, which was then explored using a combination of stronger field methods (McKay, 1992), which in turn eventually led to a collection of mathematical heuristics incorporating some of the behaviours observed in the field (McKay and Black, 2006).

It is sometimes possible to use a single case study for larger purposes (Gerring, 2007). However, great care must be taken to ensure that the single case study can be used for generalised results, and that the methods used to conduct the field study have sufficient rigour to support any claims. Gerring provides an excellent discourse on the crucial case study concept and the issues related to using a single case. When using multiple case studies, the number of case studies is important and although there is no ideal answer, a recommendation found in the literature ranges from 4 to 10 (Eisenhardt, 1989) and there are recommendations for how to analyse the data across studies (e.g., Larsson 1993).

In addition to being aware of the general guidelines for how to conduct a case study, a researcher should be aware of the most common data collection methods – interviewing and surveys. There are well established norms for how to create structured and unstructured interview sessions (e.g., Lavrakas, 1993), and how to design surveys (e.g., Stewart and Cash, 2003). Combining the methods can yield more rigorous results (Gable, 1994). Sources such as Nachmias and Nachmias (1987) give a very good overview of research methods in the social sciences and can assist with case study analysis. As case studies can have relatively few data points, methods such as non-parametric statistics can be very useful when the laws of large numbers do not apply (Siegel and Castellan, 1988).

6 Third tier: ethnographic and socio-technical methods

Case studies are usually snapshots or longitudinal collections of data involving interviews, surveys or data gathering. The next level of involvement or learning requires the use of more advanced field methods. The general field of ethnographic methods (e.g., Schensul et al., 1999; Grills, 1998; Spradley, 1979; Jorgensen, 1989; Delaney, 2004; Gummesson, 1988) provides guidance for how to participate in a culture or situation, and how to gather and analyse deeper insights. A key factor is intent and style of the interaction and role. In the most basic and initial ethnographic methods, the approach is to learn from the subjects and not to study them a priori with a model or concept. The researcher adopts a role and purpose in the community and through observation and interaction develops knowledge pertaining to relationships, terminology, concepts, and how the community evolves over time. Adopting a role and being a participant is an important element as it creates firsthand knowledge and immersion, and not arm's length data. Unfortunately, in a medical situation with possible life and death consequences, the participant's role (e.g., Participant Observation technique – Jorgensen, 1989) might be limited to infrastructure (e.g., participating in the information technology department), or as a member of a continuous improvement team. The direct operational or clinical tasks are usually performed by medically trained staff (i.e., the Charge Nurse who is responsible for resource scheduling) as the decisions involve medical terminology, knowledge of medical procedures, protocols, constraints and risks. Having an outsider independently schedule the operating rooms would be infeasible for many reasons. However, it should be possible to observe, and discuss scheduling options with the Charge Nurse, and possibly try a first pass and see what the Charge Nurse changes. Or, the observer can try to construct schedules in parallel and compare his or her efforts to the Charge Nurse's.

After an initial understanding is obtained, it is possible for the ethnographic researcher to perform an intervention or alter part of the situation to observe what happens – either in a discovery form, or in an attempt to validate a hypothesis. As noted earlier, one of the areas that help guide such endeavours is that of Action Science. In this style of research, sufficient preparatory work is undertaken to create a foundation and a causal model, and then a change is introduced. In the field of production control, working with the schedulers and simply automating what they do manually into a tool without changing roles, expectations, process, etc., is a passive style of research. Interventions such as re-designing the scheduling task, changing when tasks take place, altering the daily routine and so forth are active styles of research and fall under the Action Science style of field activity.

Both of these styles have been used in ethnographic studies (McKay and Black, 2007) and both have yielded additional insights about the dynamics and issues related to real world scheduling. Additional field methodology concepts can be translated from the socio-technological domain. Cegarra and van Wezel (2011) provide a comparison of three different field approaches for performing task analysis – normative, descriptive, and formative perspectives. They find that it is common that a field study must combine two or more of the methods for an in-depth analysis. However, they also found that not all questions required a full-scale analysis. They conclude with a suggested table of task analysis frameworks matched with different research questions. Grabot et al. (2011), and Gasser et al. (2011) use various techniques such as interaction analysis between organisation units, and decision ladder analysis from the socio-technical literature to study what planners and schedulers do in a real-world situation. Grabot et al. conducted case studies involving over 15 companies in the aeronautics and automotive sectors, and used a socio-technical view of operational interoperability to interpret the data and analyse the interrelationships between sections of the supply chain. They showed that coordination in the supply chain was not a simple technical and economic process, and that it was a complex socio-technical situation. This results in a conclusion that "stereotypical ways of performing the planning process can be grossly inadequate regarding their socio-technical specificities", and that the traditional views increase conflict situations. Gasser et al. studied a Swiss manufacturer using two theoretical models based on Naturalistic Decision Making. They found that the schedulers and planners used substantial amounts of general knowledge in their problem solving and that the schedulers were "very much dependent on a supportive socio-technical environment".

7 Fourth tier: specific methodologies

Assuming that you are probing a specific theory or hypothesis in a field (or lab) setting, you need to use appropriate research methodology. For example, if you are probing the skill of planners or schedulers, it is assumed implicitly or explicitly that generating a schedule is a cognitive task. If it is a cognitive task, then it might be possible that there is cognitive skill. If there is cognitive skill, there might be varying levels of expertise. If there is an element of expertise, then you might consider methods and concepts used to study cognitive skill and expertise. If you are probing another phenomenon, then you might consider other, suitable, research methods.

Since planning and scheduling can be considered a cognitive skill, the general topic of expertise might need to be understood at some level (see Ericsson et al., 2006; Chi et al., 1988; Ericsson and Smith, 1991; Camerer and Johnson, 1991; Colley and Beech 1989). There are differences in and outside of a laboratory setting when studying skill; Galotti (2004) and Hutchins (1995) illustrate the issues between the two situations. There are techniques for representing expert knowledge (Olson and Biolsi, 1991), and there are approaches for dealing with ill-structured problems (Voss and Post, 1988). A number of these techniques have been used to study schedulers and understand how they made decisions in rapidly changing situations requiring human judgement (McKay, 1992).

The specific methods and techniques will vary if you are probing organisational interactions and collaboration (e.g., Grabot et al., 2011) vs. the individual scheduler (e.g., Gasser et al., 2011).

8 Conclusion

Preliminary translational research between applied job shop scheduling research and applied operating room research suggests that while there are similarities, there are also differences. The empirical research on operating rooms is sparse and it is suggested that the techniques used to decompose and understand job shops can be used to gain a deeper understanding of the operating room phenomenon. Cardoen et al. state that

> "larger degree of uncertainty is the main reason why operating room scheduling urges other scheduling methodologies than the machine scheduling procedures developed for industrial systems." (Cardoen et al., 2010)

Furthermore, they conclude that the study of uncertainty facing operating rooms is the primary area requiring effort. Their academic conclusions about the importance of uncertainty are echoed by others as well (e.g., Riley and Manias, 2006; Lebowitz, 2003b; Seagull et al., 2004).

Applying tier three and four methodologies used to decompose and understand the job shop problem in factories might bear fruit in the operating room. The timing may be right to undertake such work. During the past decade, a growing number of researchers have been working at these levels in the area of production control, as evidenced by the work in Fransoo et al. (2011). This body of work is a reasonable starting point for informing applied research on operating room resource utilisation. As implied by the methodology descriptions, the methods and approaches are multi-disciplinary and are used in an interdisciplinary fashion. This requires a team of specialised researchers from different areas (e.g., operations management, ethnographics, cognitive science), or researchers who can bring a broader background to the agenda. Many of the research results noted in Fransoo et al. (2011) have been obtained by interdisciplinary teams.

As a general topic, is there a suitable way to consistently frame and pursue translational research – theory to theory, applied to applied, theory to applied, applied to theory; within a domain, between domains? Such a methodology would have to address a number of topics related to suitability, degree of structural fit, degree of data fit, and ways to support claims of suitability and success. Perhaps with more experience across multiple topics like scheduling, transportation, quality, and so forth, researchers in production control can create a taxonomy or framework that will allow translational research to be performed in a more systematic fashion and potentially allow for comparison between efforts.

Getting into the specific operational task of planning and scheduling of Operating Rooms suggests the need for multiple methods and an interdisciplinary approach – a great deal of effort, training, and time. Is the result worth it? Is this in the realm of Industrial Engineering? That is, if Industrial Engineering techniques based on mathematical principles cannot solve such problems, should we instead focus on the boundary problems? Since the early 1900s, the field of Industrial Engineering has had dual foci – of theory and application, and of boundaries and specific solutions. Application and specific solutions have often been multi- and inter-disciplinary with Industrial Engineering guidance ranging from incentives to layout designs, and organisation design to dispatching techniques. Practitioners also seek guidance on multiple fronts and want to know how to interpret boundary results in the context of practice. It is too early to claim that the effort required to understand the Operating Room problem will be worth it. In the manufacturing domain, this style of research has inspired a number of theoretical, boundary style research efforts (McKay and Black, 2006), and a practitioner's interpretation of the research (McKay and Wiers, 2004). As part of this research effort, the strengths and weaknesses of different methodologies have been discovered and shared with others who are also attempting an interdisciplinary approach to the planning and scheduling challenge (e.g., various articles in Fransoo et al., 2011). Not all research and not all researchers need to follow such an approach, but it is claimed that this style helps bridge theory and practice, and is worth the effort for those interested in this gap.

There are however, risks and challenges. It is high risk with the possibility of many biases being introduced and no new insights being generated. It is also rare that such field work can be generalisable or transferred to another site. The work can lead to other general models and theoretical research, but clean causal relationships supporting a theory are evasive. Researchers using these methods must understand and appreciate the risks and limitations of the research.

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