

# Supporting supply chain planning and scheduling decisions in the oil and chemical industry

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## Abstract

In the downstream oil and chemical industry, planning and scheduling are resource-intensive, complex, rolling processes. Decisions are taken at different stages within the supply chain (supply, manufacturing and distribution) and at different levels in the management hierarchy (planning, scheduling and operations). They differ in business scope, time horizon & resolution, data certainty & accuracy, process detail and optimizing mechanism. Aligning each step of this complex process is critical to competitive advantage. Decision support tools must therefore be provided within a coherent framework, including mechanisms which allow consistent economic and operational steering, taking due account of available (real-time) information on actual operations and market economics.

At the strategic and global planning level for a network of manufacturing plants, decisions have to be taken on feedstock procurement & distribution, utilization of production capacities, utilization of modes of transport and demand allocation. Not only existing capabilities have to be considered, but also new opportunities in all areas have to be evaluated. The resulting mathematical programming model is a mixed-integer non-linear programming (MINLP) model: integer aspects arise because of e.g. fixed costs/investment costs, tiered pricing and cargo costs. Non-linear relations are mainly caused by multiplication of quantity and economic variables. In the presentation, the various strategic planning problem areas, the contents of the MINLP aspects and the implemented solution approach will be further elaborated.

The use of such models during the aforementioned (strategic) decision-taking process yields substantial benefits not only in economic terms but also in an improved understanding of the interactions between the various components of the business.

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**Keywords:** Strategic business planning; Mixed-integer non-linear programming

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## 1. Introduction

Shell Global Solutions is a network of independent companies in the Royal Dutch/Shell Group. It is a world-class integrated research, technical services and consultancy group.

Shell Global Solutions has an international skill pool of more than 2000 specialists, in addition to that using distributed teams from within our operations. Over 100 industrial sites in more than 30 countries are advised through technical service agreements and another 550 customers are assisted on consultancy work. Our distributed service network has people around the globe. Eighty-five percent of our employees have hands-on operational experience, covering a broad range of expertise, ranging from chemical

technology via all facets of hydrocarbon logistics management to business economics, distribution and marketing, information technology and operations research, mathematics and modeling.

Our vision is to offer the best supply chain solutions in the industry by a.o. commercializing integrated decision support for the industry to

- generate initially a significant strategic advantage for early adopters, and
- eventually providing the operational standard for anyone involved in our kind of business.

Process-oriented oil and chemicals companies, like most industries, are becoming increasingly dependent on optimization tools; however we see tools as the artist's brush, we believe that it is the painter's experience, skills and creativity that makes the artwork and not the tools alone. Skills and strategy (the artist's creativity) come over a long time and with plenty of practice. We provide our clients with

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Our mission is to make **our customers the best** at responding quickly to integrated complex business opportunities.

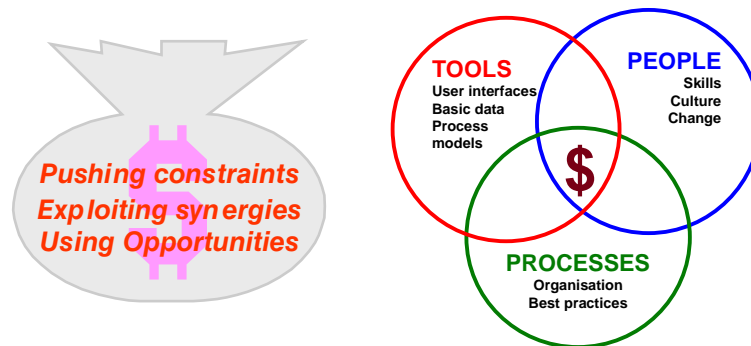


Fig. 1. People, processes and tools.

expert people who have real experience in information management, supply chain processes, organization, and tools. With our consultancy customers will be

- accessing best practice know-how from enterprises and hydrocarbon supply chains all over the globe,
- getting quick practical answers from people who have experience with solving real problems, and
- enhancing customer business vision and direction (Fig. 1).

## 2. Why supply chain?

Supply chain represents the integrated view across processes; it is a critical concept to drive coherent strategies and to manage an organization around common (end-to-end) performance objectives. Supply chain will drive productive behaviour across departmental divisions (horizontal integration) and connects the co-ordination layers of strategy, planning, scheduling and operational execution (vertical integration).

There have been a number of evolutionary stages in logistics management over the last 30 years. It is critical to understand that all of these stages are now prerequisites to achieving the supply chain vision. There are no shortcuts! Let us explain.

Companies have realized that for every step forward in the supply chain value curve (Fig. 2), it requires retrospective upgrades of all previous development stages. This is costly, and many oil and chemical companies today got bogged somewhere along this road. It is easy to identify 1970s, 1980s and 1990s companies; their capabilities have not kept track with technological development and they find it increasingly difficult to compete.

### 2.1. Data

In the 1970s, computer technology and operational research pushed the limits of data gathering past accounting into the operational areas. This has led companies for the first time towards operational visibility and performance monitoring.

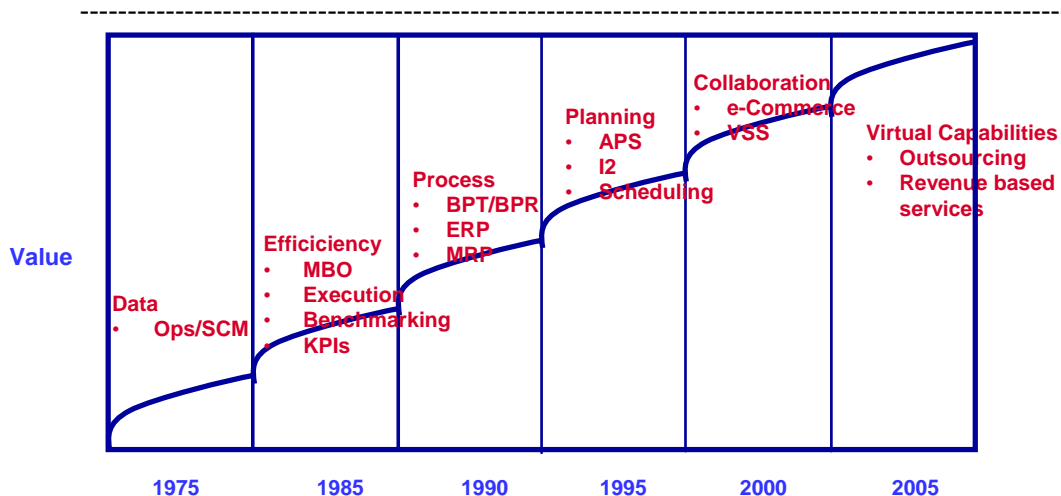


Fig. 2. The supply chain value curve.

### 2.1.1. *Validity today*

Without accurate data there is no progress possible, and the increased complexity of globalization, deregulation, tighter margins and Internet speed has accelerated this. Internet technology now enables fast, cheap communication, and data storage has become relatively low-cost.

### 2.2. *Efficiency*

By the early 1980s, progressive oil and chemical companies have started to focus heavily on operational performance. Performance management bloomed with MBO (management by objective), time and motion, benchmarking, the identification of key performance areas (KPA's) and key performance indicators (KPI's).

During this period, efficiency improvements led to a first major round of rationalization of terminal facilities and company fleets in the industry.

#### 2.2.1. *Validity today*

Unless a company can execute quickly and accurately against plan, planning is useless, and there will be little future. With high service expectations and ever-tighter margins, an efficient low-cost operation is no longer a competitive advantage for oil and chemicals companies, it is a just another entry requirement.

### 2.3. *Process*

In the 1990s the awareness grew that there is a limit to the benefit of straight efficiency; "if you run around in a circle it does not matter how fast you run." Process improvement (productivity) became the aim rather than efficiency. Accounting software companies branched out to become ERP providers (enterprise resource planners). Consulting firms became rich moving companies from efficient operations into process re-engineering as a preparation for ERP implementation. Business process transformation (BPT) and business process re-engineering (BPR) aimed to cut out unnecessary work and to streamline workflows. Oil and chemical companies changed significantly as a result of this transformation; terminal automation, computer-assisted ordering, load generation, driver loading, automated security, and the first generations of software for fleet scheduling.

#### 2.3.1. *Validity today*

The most progressive oil and chemical companies are still held back by the discontinuity of their process flows. Decisions and communications across the supply chain are ineffective and delayed, because of off-line erratic spreadsheets, misaligned performance drivers, functional barriers between departments and a lack of transparency across. This all leads to slow and inept day-to-day decisions that cost companies dearly in terms of financial performance.

### 2.4. *Planning*

Planning and strategic positioning go hand in hand. How can a company maximize profitability in an ever more competitive and commoditized market. How can companies with long supply lines react quickly in a volatile, more transparent and global marketplace? Planning capabilities have developed over the last 10–15 years to translate strategic and operational objectives into computer-assisted plans and schedules.

#### 2.4.1. *Validity today*

Supply chains must continuously align with market forces and commercial opportunities. Market volatility can only be countered by increased flexibility and speed. This requires a change by companies from their current more or less 'steady-state' planning (LP-basis) and mid-term economic steering to near real-time planning that allows on-the-run changes, based on current marginal economics. This requires ever-shorter review periods and planning cycles and management by exception. Planning will be otherwise ineffective to direct trading, refining, marketing and supply chain trade-offs.

### 2.5. *Collaboration*

Agility and speed are achieved by aligning information, performance, people and tools around critical processes. This speed and connectivity requires both horizontal and vertical integration and is a function of how information is extracted, exchanged and communicated.

#### 2.5.1. *Validity today*

It does not require a genius to realize that people, spreadsheets, meetings, accounting cycles and phone calls all stand in the way of speed.

Computer and workflow-assisted collaboration is therefore a critical functionality and allows processes to become as virtual as possible. Let me illustrate this with a simple example. Most of us ask our secretary to book a flight; she would order this from a travel agent, who would check with the airline, who then would advise availability. If not available, the secretary would ask for an alternative timeslot, and the process will be repeated. With Internet connectivity, strategic sourcing and electronic ticketing, this process has become virtual, with no need for any intermediation. Virtualization replaces people-to-people stagnation, with people-to-context speed and flow. There are many virtualization opportunities in supply chain processes:

- orders to loads to distribution to payment,
- product flows to accounting to reporting and performance,
- strategic objectives to planning to scheduling,
- employee to EHS,
- operational execution to policy and procedures, and
- sales to inventory to manufacture to purchasing.

## 2.6. Virtual capabilities/supply chains

The virtualization of the above processes will lead eventually to the virtualization of whole supply chains. The financial success of a company will be determined by accurate and timely data, productivity and tight execution against plan assisted by transparency and integration. High-tech companies have proven that in a competitive commoditized market, assets are no longer a means to differentiate. It will be the supply chain capabilities that make a difference over the next 5–10 years and companies will get used to investing into the associated technology.

We at Shell have therefore picked up the gauntlet for our own business and we are developing this technology as the new open industry standard. Why an industry standard? The reason is simple: It is not possible to build a virtual supply chain and hope to collaborate within a non-virtual world. We need to connect to others!

## 3. Integrated planning

Tools that are designed for economic and operational steering must take account of available information (real-time and forward view) that reflect the actual operations and current market economics. Today different decisions are supported by sets of different tools. Shell is working continuously to integrate these tools to support the entire decision process. Horizontal and vertical integration aspects are visualized in Fig. 3.

### 3.1. The holy grail of full integration

Even with a very comprehensive set of tools in the industry, and spanning the entire supply chain, Shell had not achieved this true integration. The next step required us to plumb the tools together and go the full way, with decision support and workflow functionality.

A vice president of Shell Oil Products has recently summarized this as follows:

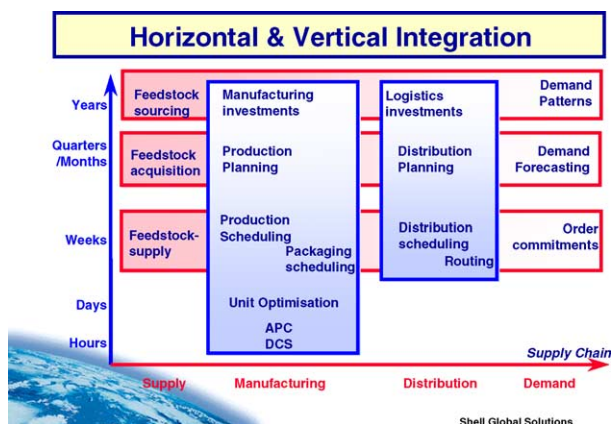


Fig. 3. Horizontal and vertical integration.

"The most successful e-supply initiatives so far have been in industries where the components converge to create a product and where prices are not volatile. Energy is different. The supply chain is divergent; there are more products than raw materials and prices are highly volatile. Shell understands this and is aiming to create a reliable, real-time, multi-point-optimized, and overview of the entire supply chain. It is seeking to set the standard of innovation, effectiveness and efficiency in the downstream oil industry.

Across the globe this initiative has the potential to generate new value and drive savings to the tune of a multiple of million US dollars a day."

For the vision we specified the core requirements for such an integrated toolset:

- *Complete horizontal supply chain integration*—a seamless system from crude/feedstock trading through to product trading
- *Convergence of strategy, planning and scheduling*—vertical systems integration
- *Modularity* to enable a phased implementation and customization—with open architecture and data model support
- *Scalability* for application to the most simple and or complex supply chains
- *Interactive*, customized viewing by different members of a distributed organization—obviously Internet- and workflow-enabled
- *User-interfacing* through a revolutionary 3D, virtual landscape
- Real-time optimization speed after any update—incorporating real-time margin reconciliation
- *Direct links* to online refinery/plant optimization

## 4. Strategic and global planning

Returning to current practice, at the strategic planning level, tools should cover the entire supply chain both in terms of materials and in terms of geographical areas involved. Furthermore, they are particularly fit for supporting what-if studies. Their relative strength is modeling and optimization flexibility. Their weakness is a limited capacity for handling massive amounts of operational (dynamic) data. The next part of this paper will address both services and tool offers in the strategic business planning area. Shell Global Solutions is intensively involved across the oil, chemical and gas business.

For the oil sector we provide end-to-end supply chain and network optimization across feedstock, manufacturing, exchanges, blending across supply/distribution terminals and depots, and into demand, channel segmentation. With one client we have 16,000 stations modeled! The primary optimization variable is integrated margin; however others like

lowest cost at set customer service level by channel can be used.

For chemicals business we provide regional and global strategic studies, and optimization across feedstock, manufacturing facilities, product rationalization, compounding and end-user analysis and rationalization in warehousing and distribution.

In the gas sector we offer complete corridor planning services, from construction to production, to end-user (optimizing overall margins), and forward planning in terms of gas specifications, gas/crude production balancing, the effect of a no-flaring policy, and debottlenecking of multiple gas trains.

The toolset is known as GMOS/NetSim (**G**lobal **M**anufacturing and logistics **O**ptimization **S**ystem/**N**etwork analysis and **S**upply chain **o**ptimization **S**ystem).

In the remainder of the paper we will focus on GMOS/NetSim in the chemical sector; however as stated earlier we are equally strong in the other sectors.

The value of the GMOS/NetSim tool is in its state-of-the-art functionality, the product is mature and has a large user group, regular updates/improvements in new releases and long-term support continuity. This valuable tool helps our clients to define an optimal asset structure, and within that achieve

- optimal sourcing of raw materials,
- balancing yields against both the market value of alternative raw materials and derivatives,
- optimizing manufacturing volumes by plant, driven through tranching/tiered pricing or price elasticity functions,
- deciding where to manufacture, and
- how to minimize the logistics distribution cost.

#### 4.1. How is GMOS/NetSim different from traditional LPs?

- It covers the end-to-end supply chain, from raw material to intermediates (e.g. monomer), to finished product grades to the end customer.
- Solves both non-linear and mixed-integer problems, with graphical user-interaction and constraint-analyzing facilities.
- GMOS/NetSim modular approach allows optimization between multiple manufacturing plants, packaging locations and distribution modes for both your in-house and third-party operations, taking joint venture/ownership aspects into account.
- The model can offer optimization of grades production at a component/specification level.
- Movements and storage of products can be tuned to reduce tax, import tariffs and duties.
- A structured navigator manages the data residing within workbooks and database files, and therefore the user has full control over the data.
- The analysis of solutions is transparent and analysis by sensitivity calculations is robust (Fig. 4).

#### 4.2. GMOS/NetSim enhances the bottom line in a number of ways

From our experience, such a combination of effective sourcing and decreased manufacturing/distribution cost is achievable and will provide you with a significant upside to your current overall profitability.

The model has improved the profitability for our customers by enabling enhanced strategic and tactical decision-making. Here are some examples:

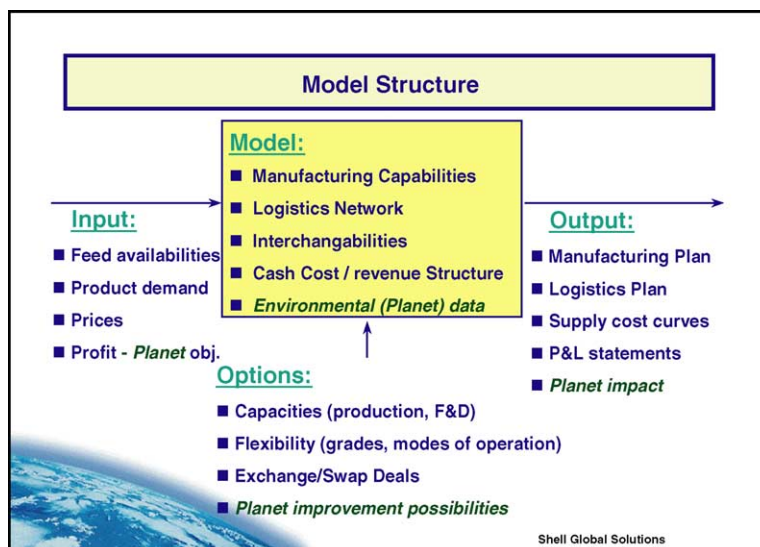


Fig. 4. Model structure.



- Network rationalization of manufacturing plants, distribution centres and transport modes, within and across country boundaries
- Rationalization of the product slate in terms of available grades and alternative sourcing
- Optimal routing through primary and secondary distribution to minimize the overall cost of supply
- GMOS/NetSim provides meaningful scenario analysis through case management and has detailed reporting

#### 4.3. What would a migration path look like for your operation?

As covered earlier, Shell Global Solutions provides all aspects of industry support and services and there is no consulting or software firm which can match our hands-on expertise. Shell Global Solutions is an independent corporate entity and we are therefore completely impartial; confidentiality for our clients is absolutely assured. We have a proven methodology for executing GMOS/NetSim projects:

- Identifying the owner of the GMOS/NetSim model and defining the business processes
- Feasibility study
- Functional specification
  - Scope of the model
  - Granularity of the model
- Data-gathering phase
- Model-building phase
- Validation of the model
- Training and documentation

## 5. GMOS/NetSim in more detail

### 5.1. The algorithm

GMOS/NetSim employs a mixed-integer non-linear programming (MINLP) technique. Today, MINLP techniques

may still be considered as more advanced optimization techniques. In general, optimization algorithms systematically move degrees of freedom within predefined bounds such that the objective function is maximized without violating constraints imposed on dependant variables. MINLP algorithms have the capability to simultaneously evaluate the impact of choices for integer (0–1 or on–off) and continuous variables (e.g. plant loading) on the objective function, subject to the non-violation of non-linear constraints. Non-linear aspects are handled via a combination of successive mixed-integer programming and rigorous non-linear programming (NLP) solvers.

In Kallrath (2000), an overview is given of the potential benefits of mathematical programming, what kind of problems can be tackled and a state-of-the-art view on good modeling practices and algorithms. Going into more detail on MINLP problems, Grossmann (2002) gives a review of possible solution algorithms. Using Grossmann's classification, the solution algorithm implemented in GMOS/NetSim belongs to the category LP/NLP-based branch and bound, where for each node in the branch and bound tree an NLP sub-problem with fixed-integer variables is solved. In Floudas (1995), detailed theory and methods for MINLP and their applications can be found. As software environment, a combination of the mathematical modeling system AIMMS (<http://www.aimms.com/>), the mixed-integer solver CPLEX (<http://wwwilog.com/products/cplex/>) and the non-linear solver CONOPT (<http://www.conopt.com/>) is used.

A global overview of the GMOS/NetSim functionality can be found in the picture below (Fig. 5). The following provides a more elaborate description of degrees of freedom and constraints.

### 5.2. Constraints and data requirements

Degrees of freedom are subject to the operating window of a business given by the following constraints:

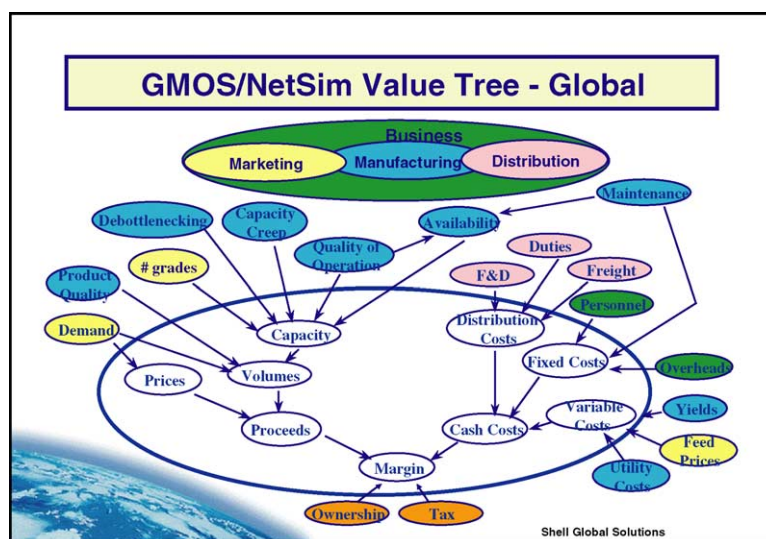


Fig. 5. Global value tree.

- Manufacturing capabilities, including filling and dispatch restrictions
- Transportation network (for feed supply and product distribution)
- Cash cost structure: variable and fixed costs for feed supply, manufacturing, product distribution (all in local currencies)
- Interchangability of products and intermediate products
- Availability and prices of feedstocks per supply point
- Product demand and product prices per demand area

The latter two constraints have to be updated so frequently that they have been referred to as ‘inputs’ for GMOS/NetSim. All the other data elements are more or less fixed. They only change at the expense of capital (e.g. capacity) or a significant technological effort (e.g. yields).

With respect to manufacturing capabilities, data are required with respect to

- capacity per product per processing line, including filling and dispatch capacities,
- stream days per processing line, including filling and dispatch,
- yield data per product and per processing line (not only feed requirements per ton of product, but also utility demands and chemicals per ton of product),
- by-product yields,
- full specification blending from components with the possibility to use any non-linear blend rule, and
- stock limits.

GMOS/NetSim determines the network for transport of feeds, intermediate products to manufacturing sites and distribution of finished products to demand areas, based on production possibilities (grades).

To model the cash cost structure of this business, data are required for the following:

- Cost of feed supply per supply points. This is the aggregate of feed purchase cost, packaging costs, transport cost to port, freight from port to port (all ports connected to manufacturing plants), feed handling cost in receiving port, import duty in receiving manufacturing plant
- Site overheads (including costs of site closure)
- Fixed costs per processing line and per filling and dispatch facility
- Costs of utilities/chemicals
- Product distribution costs, comprising packaging cost, transport cost to port, freight from port to port of demand areas, handling at receiving location, import duties on (calculated) transfer prices, profit margin of a manufacturing location (in case of supply of intermediate products) for various modes of transport, including ships
- Stock-holding and terminal handling costs

All costs are specified in ‘local’ currencies at the location, except for freight, which is specified in USD/t.

GMOS/NetSim provides the user the possibility to define in which currency optimization and reporting needs to be carried out.

With respect to product demand, the user may choose for

- either minimum/maximum or fixed demand: per SKU (product per pack and dispatch type), and per market segment, and at
- either a fixed or flexible price (price elasticity, tiered/tranched pricing).

### 5.3. Miscellaneous issues

- All data can be entered for a series of periods. The optimization will be done for a user-specified subset of periods, resulting in a multi-period model
- GMOS/NetSim can run a ‘base-case’ using actual production figures from a reference period
- Optimization can also be carried out in ‘margin-mode’. In this case GMOS/NetSim excludes fixed costs from the objective function
- The functionality of GMOS/NetSim includes the option for users to model the impact of grade switches on stream days for any processing line
- Possibility to specify yields as a function of cumulative throughput (e.g. catalyst usage)
- Next to optimizing an economic objective it is also possible to evaluate the environmental impact of the supply chain. To do so for all activities in the supply chain data has to be specified for the environmental aspects to be modeled together with conversion factors to bring them to one separate objective function. An example is the conversion from exhaust gas to CO<sub>2</sub> equivalent to global warming potential

### 5.4. Evaluation of investment options

GMOS/NetSim allows users to evaluate investment options. Every investment or divestment option affects the operating window of a business. For every option the user has to define the impact of the investment on

- number of stream-days,
- required processing line capacity by product, and
- sought filling and dispatch capacity.

The associated investment is then modeled as a fixed-cost capital charge.

GMOS/NetSim considers investment options as integer variables and optimizes for the most attractive one from the perspective of the objective function. Sensitivity analysis may be carried out to assess the robustness of the preferred option to its underlying assumptions. Furthermore, GMOS/NetSim allows the user to link different options.

### 5.5. Mixed-integer and non-linear aspects

Mixed-integer aspects are caused by amongst others the following aspects:

- Fixed costs/cost of closure for processing equipment, manufacturing site and/or depots/warehouses
- Minimum turndown levels
- Non-monotonous tiered/tranched pricing for feeds and products
- Transport costs per trip instead of per amount
- Switch-over times for grade switches
- Limited number of suppliers to a site
- Exchange/swap deals with fixed costs/revenues
- Investment/divestment options
- Yields as function of cumulative throughput—piecewise linear modelling
- Optimal timing of catalyst switches

Non-linear aspects arise amongst others from

- Duty on transports between countries
- Tax regulations
- Non-linear blend rules
- Non-linear behaviour of plants as a function of cumulative throughput (e.g. catalyst utilization)

## 6. Application example

GMOS/NetSim is used extensively in the oil, chemicals and gas business for strategic and tactical decision-making (consultancy) studies. A current gas production and distribution model takes 100,000 rows, over 90,000 variables of which nearly 16,000 are integer. This shows the complexity that GMOS/NetSim can deal with.

For strategic studies GMOS/NetSim models are frequently used in workshops to assist a team of global

representatives of various business areas (manufacturing, marketing, strategy and planning) to develop options for reducing their cash costs.

## 7. Conclusion

A prerequisite for optimal usage of the supply chain is the implementation of all development stages in the supply chain value curve (Fig. 2). The ultimate goal is a virtualization of the whole supply chain having as core requirements the following: complete *horizontal integration* (a seamless system from crude/feedstock trading through to product trading); *convergence* of strategy, planning and scheduling (vertical systems integration); *modularity* to enable a phased implementation and customization; *scalability* for application to the most simple and or complex supply chains; *interactive, customized viewing*—obviously Internet- and workflow-enabled; *real-time optimization speed*; *direct links* to online refinery/plant optimization.

Modeling all aspects needed for strategic planning of a truly global supply chain results in large scale MINLP problems, which can nowadays be solved using an appropriate combination of successive mixed-integer programming and rigorous NLP solvers.

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