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Business Decision Making in the Chemical Industry: PSE Opportunities

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Abstract

The chemical enterprise of today faces a complex, global, and increasingly competitive environment, one with numerous market prospects and fraught with endless uncertainties. All enterprise-level decisions related to project, product as well as process selection, supply chain design and management, manufacturing, and logistics must carefully consider the various opportunities as well as the uncertainties and risk. In this paper, we examine the role that the Process Systems Engineering community can play at this interface of business and engineering.

1. Introduction

The realization that a butterfly flapping its wings in the Amazon could result in a thunderstorm in Australia is usually attributed to the meteorologist Edward Lorenz who observed in simulations of weather patterns that a small change in the initial conditions can lead to a massive turmoil further down the line. This anecdote is typically used to highlight the interrelatedness of the complex meteorological system and the resulting complexity. The same is becoming true of enterprises in the globalized “flat world” of today [1], where intercontinental connectivity is prevalent. As exemplified by recent events – the soaring crude oil prices; the declaration by Chevron Oronite of force majeure in 2005 and the consequent oil additives rationing by many suppliers; and the spread of the avian flu and the Tamiflu shortage – various types of “hurricanes” buffet most businesses regularly. “Business Decision Making” involves managing the enterprise in the face of such “hurricanes”.

Any manufacturing business can be considered to be an amalgamation of at least four intertwined networks:

- Manufacturing network (dealing with production)
- Services network (dealing with support services such as logistics)

- Innovation network (dealing with development of new products/services)
- Finance network (dealing with capital investment & working capital)

Historically, the four networks have been operated largely in isolation and have been the subject of study of different communities. The following classes of decisions are common to each as summarized in Table 1:

- Structural (design) decisions
- Resource allocation decisions
- Operational decisions

Table 1: Similarity of business decisions among the networks

Decisions	Manufacturing / Services Network	Innovation Network	Finance Network
Structural	Plan / develop network capacities, structure (production, distribution centers, supplier / customer selection)	Plan product discovery / development	Plan structure & raise capital (equity vs. debt, dividends, M&A)
Resource allocation	Allocating production to plants; Allocating manufacturing resources to products	Allocating resources to leads	Portfolio management; Capital budgeting
Operational	Measurement, control, planning, scheduling, monitoring & disruption management; E.g.: Demand forecasting	Measurement, control, planning, scheduling, monitoring & management of innovation tasks E.g.: Market research, clinical trials	Measurement, control, monitoring & management of financial resources E.g.: treasury functions, currency, asset hedging

The rest of this paper focuses on decisions involved in managing the four aforementioned networks. Specific emphasis is on the manufacturing / services networks which have received the most attention to date in PSE.

2. NETWORKS IN THE CHEMICAL INDUSTRY

At first sight, businesses in the chemical industry seem to have many features in common with other high-tech manufacturing industries such as electronics. As highlighted by Chandler [2] there are however major differences: (1) the infrastructure that made mass production and distribution possible in the chemical industry – transportation (steamships, steam-powered railroads) and communication (telegraph and the transatlantic cable) – came of age in the 1880s; the infrastructure for the electronics industry began much later in the 1950s. (2) A small number of companies were initially engaged in commercializing new products in the electronics industry – vacuum tube, transistor, integrated circuits and the microprocessor. In contrast, a much larger number of technologies based on chemical and biological sciences became available for the chemical industry and these were commercialized by at least fifty chemical and thirty pharmaceutical companies. (3) The products from the chemical industry utilized the new technologies to create new materials and medicine that replaced natural ones in contrast to the electronics industry which developed "novel" products for the consumer markets and thus reshaped the nature of life and work.

These historical quirks of the chemical industry endure thus far and lead to some unusual features in chemical enterprises. Because of these, the plethora of research in enterprise optimization and supply chain management for other discrete manufacturing industries, does not port very well to the process-based chemical industry. In the next section, we review some of these distinguishing factors, particularly in the context of process industry supply chains.

A primary feature of chemical supply chains is the huge variety of non-discrete, immiscible, incompatible, non-substitutable, and huge-volume products, each of which has its own unique characteristics. The concepts of "discrete parts" and "assembly" simply do not exist in chemical manufacturing. The industry is highly capital-intensive with long and divergent supply chains with recycle loops. The industry is the biggest consumer of itself and many of its businesses are high-volume and low-margin. Maritime transport is the workhorse of chemical supply chains and the hazardous nature and huge volumes of chemicals necessitate the use of highly expensive and sophisticated transport equipment and storage facilities that require complex and expensive cleaning procedures and maintenance, and result in long lead times. The logistics costs in the chemical industry could be as high as 20-30% of the purchase cost [4]. Huge inventories that are critical to the continuity and profitability; need for safety-first; sensitivity to oil prices, sociopolitical uncertainties, environmental regulations; and extensive trading are the other key features of the chemical industry, which set them apart easily from the other supply chains. Needless to say, the general supply chain research that has mainly focused on the computer industry has been oblivious to most of these complexities and features.

While the above broad features distinguish the chemical industry as a whole, there are further fine-grained differences even among its various segments such as refining, lubricant additives (as one example of specialty chemicals), and pharmaceuticals. These distinguishing features are summarized in Table 2. These essential differences reflect themselves in two of the most essential aspects of any business – logistics and economics – as summarized in Table 3.

Table 2: Key differentiating factors among the principal sectors of the chemical industry

	Refinery	**Lube Additives**	**Pharmaceuticals**
Nature of product	Undifferentiated	Partial differentiation	Differentiated
Form of product	Fluids	Predominantly viscous fluids	Predominantly solids
Product definition	Specs based (undifferentiated)	Performance centric	Molecule centric
Product hazards	Flammable	Mixed	Safe
Nature of industry	Low margin, high throughput	High-value, low throughput	High-value, low throughput
Core competency	Process & technologies	Formulation	Product innovation
Uniqueness of process / technology	Mostly similar between competitors	Unique intellectual properties	Unique intellectual properties
New product	New grades through blending	New products through blending	New molecule
Nature of processing	Continuous; high throughput	Batch; low throughput	Batch; low throughput
Nature of operation	Separations centric	Blending centric	Reaction centric
Complexity of operation	High & automated	Low (no reactions)	Low-Medium
Waste treatment	Wastewater treatment	Limited	Water; heavy metals - incineration
Asset costs	High	Low	Low-Medium
Type of customer	Consumer / business	Business	Consumer / government / business

3. DECISIONS AND SUPPORT TECHNIQUES

Arising from the differing characteristics, the key business decision problems summarized in Table 1 are of varying importance in the three sectors. Table 4 summarizes the nature and type of some of the common business decisions. Many of these have received substantial attention in the literature. Special-purpose decision support techniques broadly based on control theory, optimization, and artificial intelligence have been developed as reported in several excellent reviews [5]-[7].

Table 3: Logistics and economic factors in the principal sectors of the chemical industry

	Refinery	**Lube Additives**	**Pharmaceuticals**
Mode of logistics	Sea most prevalent	Mix of land & sea	Air is predominant
Packaging	Bulk	Drums & Isotankers	Mix
Supply chain operation mechanism	Push	Pull	Push
Inventory	High volume; short term	Low volume; short term	Low volume; long term
Procurement cycle length	Months	Weeks	Weeks
Delivery lead times	Weeks	Month	Days-Weeks
Product Trading across Competitors	Prevalent	Some	Uncommon
Product Variety (# of SKUs)	Small	Medium	High
Barriers to cross-border supply	Low	Medium	High (Regulatory factors)
Key supply chain player	Oil suppliers	Customer	Company
Supply chain KPIs	Inventory	Customer satisfaction	Mix
Business Growth Rate	High	Medium	Low-medium
Predominant cost factor	Crude price	Mixed	R&D (product innovation) & Marketing
Raw material costs	Critical	Important	Important
Operation costs	High	Low	Medium
Pricing variations across countries	Low	Medium	High
Nature of product pricing	Cost + margin based	Performance based	Market & innovation based

Supply chain problems were traditionally considered in isolation before the supply chain perspective came into vogue. Optimization-based approaches have been the workhorse for a variety of the constituent problems in supply chains including planning, scheduling, inventory management, transportation, capacity expansion, etc. However, classical optimization techniques have been less successful in dealing with large-scale, integrated, dynamic, uncertain problems in real supply chains. Therefore, at present, simulation remains the predominant methodology for dealing with such systems. Specifically, with the widespread availability of easy-to-use simulation tools, most companies resort to Monte Carlo type studies. It should however be noted that neither of the two is a panacea for all enterprise optimization problems; each has its own distinct yet complementary advantages, which motivate their synergistic union. The simulation-optimization framework [8] provides one way of achieving this. Agent-based approaches [9] provide an alternative scalable solution to seamlessly integrate heterogeneous methodologies.

We have explored some of the above avenues to address various problems in chemical supply chains. For instance, mathematical programming approaches seem best suited for well-determined deterministic problems such as refinery scheduling [10], capacity expansion [11] & [12], logistics [13], etc. On the other hand, simulation methodologies [9] & [14] are ideal when a decision has an impact across the supply chain and must be considered in its entirety (for e.g. crude procurement).

3.1. Refinery Supply Chain Simulator IRIS:

As a first step in modeling oil and gas supply chains, we have developed a dynamic simulator, called Integrated Refinery In Silico (IRIS), for refinery supply chain simulation and analysis. Figure 1 shows a detailed block diagram of IRIS with various blocks representing supply chain entities and the connections represent information or material flow. The different types of blocks in IRIS are:

- Refinery external entities (Supplier, Customer, Port)
- Refinery functional departments (Procurement, Operations, Sales, Storage)
- Refinery processes/units (Pipeline, inventory, CDU, Reformer, Cracker)
- Refinery SC Policies (Procurement policy, Planning, Scheduling, Storage policy)
- Refinery Economics

IRIS has been implemented in Simulink and is an effective tool for evaluating real what-if scenarios. It can serve as a holistic test-bed for the evaluation of supply chain methodologies and algorithms. The interested reader is referred to [14] for a detailed description of this dynamic supply chain model.

4. Role of PSE in Business Decision-Making

Process systems engineering vis-à-vis business decision making is today at the same juncture that it was in the 1970s with computing and process control. The emphasis in those days [15] was in developing dynamic models of the process and general-purpose dynamic simulation algorithms. The availability of the dynamic models led to the mushrooming of research in advanced process control, monitoring, diagnosis, etc. with emphasis on the development of techniques and tools to handle processing disturbances and uncertainties. PSE has arrived at a similar doorstep today vis-à-vis business decision making. With the availability of dynamic models of business networks, various types of business decisions can be supported using PSE tools and techniques. The emphasis on handling uncertainties through systematic approaches would continue and extend to this new domain as well. We outline a few possibilities next.

Table 4: Key business challenges in the principal sectors of the chemical industry

	Refinery	**Lube Additives**	**Pharmaceuticals**
Capacity planning	Debottlenecking & adding units in existing facilities	New facilities	New facilities
Production planning	Supply chain integration with process complexity	Integrating production with delivery	New product introduction
Production scheduling	Crude / product blending; throughput scheduling	Order scheduling	Campaign scheduling
Control	Advanced / model-based	Manual	Manual
Measurement	Real-time	Lab-based	Lab-based (ref to PAT)
Fault diagnosis & recovery	Complex	Easy	Not allowed (ref to PAT)
Equipment monitoring	High importance	Low importance	Low importance
Process optimization	High	Low	Medium
Demand Forecasting	Critical	Low	Medium
Risk management & uncertainties	Raw material pricing	Production uncertainties	R&D
Logistics	Ship routing; pipeline optimization	Multi-modal network design	Integrated optimization of supplier selection and logistics
Solution Methodologies	Process simulation (Steady & dynamic); Business simulation; Model-based control; SPC; Spreadsheet; Math Programming; AI approaches; Manual / experience based /Heuristic approaches	Business simulation; SPC; Spreadsheet; Manual / experience based /Heuristic approaches	Business simulation; Batch control; SPC; Spreadsheet; Manual / experience based /Heuristic approaches

Disruptions can be defined as any event or situation that causes deviation from normal or planned operations. Among the possible causes of disruption are operational difficulties, emergency shutdown, natural disasters, terrorist incidents, industrial actions (e.g. strikes, protests), and accidents (in-plant, or during transportation). Root causes for disruptions are often human error, wrong information, and poor planning or forecasting. Disruptions bring about adverse effects such as blockage of material flow, loss of ability to deliver the right quantity of the right product at the right place and at the right time, inability to meet quality requirements, loss of cost efficiency, under- or over-supply, process shutdown. All of these translate into financial losses, directly or indirectly and motivate the development of simulation models and decision support systems for managing disruptions in the supply chain. Some common disruptions in a refinery supply chain include delays in crude oil arrivals, crude oil being out-of-spec, unexpected changes in product distribution, unavailable or constrained plant units, and demand fluctuations. Such disruptions are not infrequent. For example, every month there are four to five occasions on average, when crude transportation by sea to the refinery is delayed. Similarly, use of crude oil from storage is constrained 4-5 times each month due to entrained rainwater. The liberal outsourcing of logistics activities has broken supply chains into independent entities that are inherently different. In many instances, this can introduce delays and disruptions in material and information flows. Thus, disruptions are a fact of everyday life in all supply chains and preventing them or mitigating their impact has become an important issue in supply chains.

Simulators serve as a ready tool for managing business network disruptions. They can provide decision support in the face of uncertainties [16]. Thus, uncertainties in events such as crude delivery or in information such as product demands can be dealt with by embedding the appropriate decision processes within the same framework. Also, the simulation approach can be naturally integrated with optimization especially through the agent-based framework. With the availability of dynamic models, process control methodologies which have historically sought to eliminate the effect of process disturbances can be extended to handle business disruptions. Feedback, feedforward, and advanced control systems can be designed for enterprises [17]. Process identification techniques would be necessary for business process identification. Sensor selection and network design techniques would find analogues in business metrics and key performance indicators. Process monitoring, fault diagnosis, and abnormal situation management technologies can be extended to disruption management.

The above examples dealt with operational decisions. However, business network models can play a major role in structural decisions as well. One such example is systematic risk identification and management in business networks. Approaches such as Hazard & Operability (HAZOP) studies, fault tree analysis, and other process safety management techniques commonly used in the PSE community can be extended to business networks as well. Once all important risks have been identified, sensitivity studies can be performed and the supply chain structure (eg: identification of alternate suppliers) and policies optimized for robustness.

Finally, a key strength of the PSE community has been its ability to continually imbibe new ideas and concepts from other domains (eg: bio-, nano-, etc). This ability would become essential once more in the context of financial networks. With a few exceptions [18], the PSE community has shied away from the fundamentals of financial management. These considerations in various forms – structural, resource allocation, and operational – would be essential if PSE seeks to serve a central role in the businesses of the 21st century.

4.1. Impact of PSE :

The truly widespread use of process simulators such as Aspen-Plus, Hysys, Pro II, gPROMS, etc. in continuous chemical plants is an irrefutable example of the impact of PSE techniques on plant operations. The impact on business decision making, on the other hand, is relatively less documented. This is certainly not because the potential impact is lower. Two excellent examples of the scale of the impact exist in the operations research literature. First, Camm et al. [19] reported an optimization study for restructuring the supply chain network of Proctor & Gamble. Based on this study, P&G reduced its North American plants by almost twenty percent, wrote off over a billion US$ in assets & people transition costs, and saved well over US$250 million (before tax) per year. Second, Lee & Chen [20] reported a web-based production planning tool at BASF, which cut down production scheduling time from several days to a few seconds and reduced inventory and improved BASF's use of production and storage capacities. So far, we have not found any similar success story in the PSE literature.

This paucity could be because the PSE research on business decision-making is still in its infancy. Alternatively, this may be due to the cloak of confidentiality that surrounds business procedures, decisions, and impacts. For instance, the refining industry has been the single largest user of PSE techniques such as linear programming for several decades now. But well-documented impact reports are hard to find. Of course, nobody can doubt the impact of optimization on business decision-making in that industry. Recently, Kelly & Mann [21; 22] estimated that the use of advanced optimization techniques can save as much as $2.85 million/year in crude oil scheduling alone. It has been estimated [23] that even this number is easily dwarfed by the potential impact on crude transportation, which can run in tens or even hundreds of millions. Recently, we performed a logistics study [24] as part of a consulting project for a major multinational company, which concluded that roughly $750,000 per year (24%) could be saved through a systematic optimization of the company's inbound logistics operations alone. The company used our study and analysis as the basis for a major business decision. The above examples, based merely on our own knowledge, probably represent only a small fraction of the impact stories in the literature. But surely, a huge number of impact stories go unreported and undocumented. It is in the interest of the PSE community and the chemical industry to widely report such success stories and case studies in the PSE literature in particular and thereby stimulate further research and increase awareness of PSE tools and techniques for business decision making.

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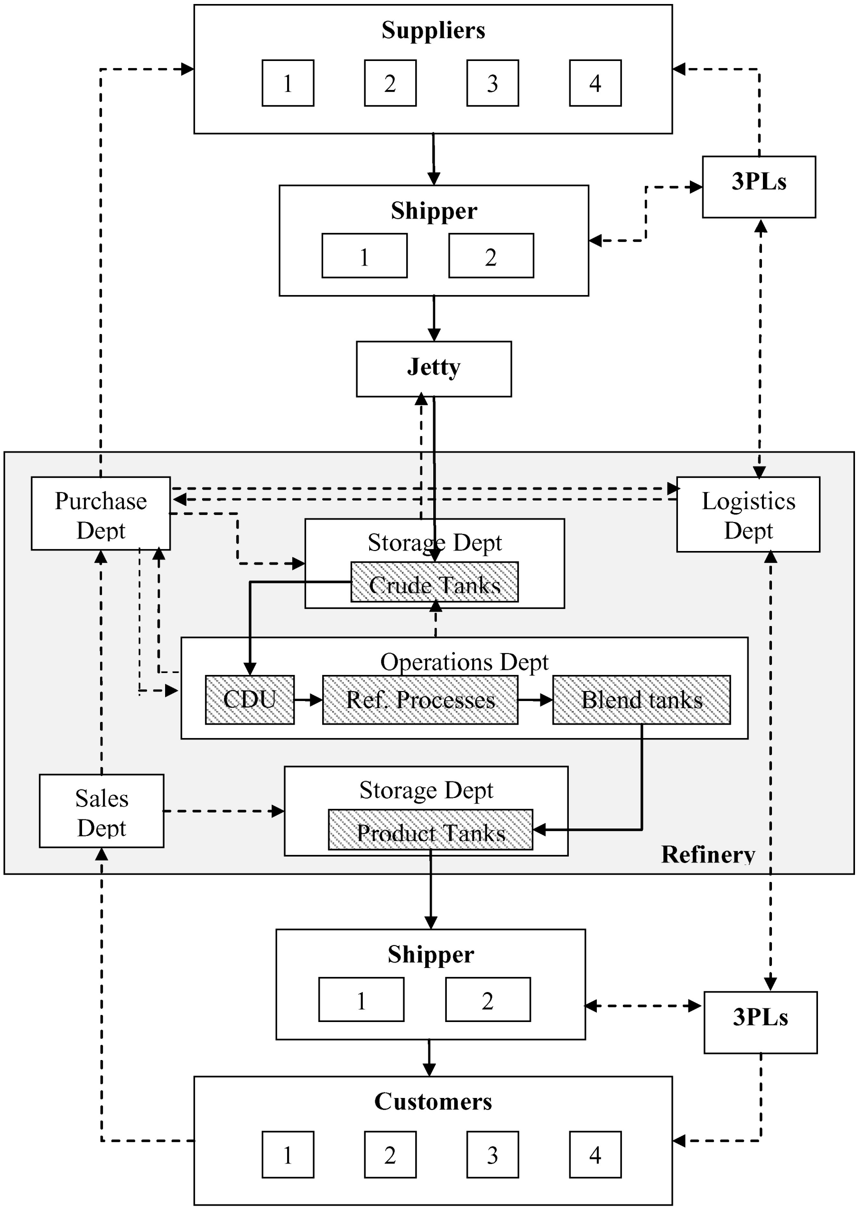

Figure 1. Schematic diagram of a refinery supply chain