COMPUTER-INTEGRATED MANUFACTURING IN THE CHEMICAL INDUSTRY

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Computer-integrated manufacturing (CIM) for discrete manufacturers has received much attention in recent years. In the process industries the new concept of CIM has been largely ignored. In this article we will try to indicate valuable potential uses of CIM in the process industries; in particular, the chemical industry. However, due to the inherent differences in the nature of operations as opposed to discrete manufacturing, process industries may need to adopt particular management techniques in order to successfully implement CIM. This is captured in a list of focal points, after comparison of specific characteristics that separate process industries from discrete manufacturers. The chemical industry is used as being representative of the process industry in general.

THE PROCESS INDUSTRY

The definition of a process industry in the *APICS Dictionary* states:

> Process industries are businesses that add value to materials by mixing, separating, forming or chemical reactions. Processes may be either continuous or batch and usually require rigid process control and high capital investment [1].

Typical examples of process industries include the chemical industry, petroleum industry, paper manufacturing, and the food and beverages branch. Their relative position with respect to product and process organization is illustrated in the product-process matrix of Hayes and Wheelwright [5] as shown in Figure 1.

Table 1 lists the major differences between the process industries and the discrete industry in relation to the market, the production process, the quality of products and processes, and planning and control [9,11,12]. With respect to the difference in automation, one can observe that in the process industries the automation of the production process itself is highly developed, while in the discrete industry the automation of the planning and control system is emphasized. Process industries can be categorized along different characteristics. One of them is the division of the industry by type of products, resulting in nine groups [9]:

1. Food
2. Paper and cardboard
3. Chemicals
4. Raw oil
5. Rubber and plastics
6. Building materials
7. Pottery and glass
8. Primary metal
9. Energy.

A convenient way of classifying chemical industries, apart from categorizing them by product, is by process structure. Process structure plays a central role in defining the production planning problem, and is commonly categorized as single-stage processes and multistage processes, which can be further subdivided into parallel and serial-unit processes. Figure 2 shows such a classification. Note that in Figure 2 the same divisions hold in a single-product environment, whereas parallel-unit processes or parallel serial-unit processes are not further subdivided, because the process units are always dedicated to only one product.

Each class can be characterized further as either a continuous or semi-continuous production process. Each may have intermediate or no-intermediate storage (tank, bin, etc.). The production process with intermediate storage can be further subdivided as:

- Unlimited in size
- Limited in size
- Non-dedicated
- Dedicated to certain products
- A mix of the above.

The production process with no-intermediate storage can be further subdivided in:

- Stable product where the unit processor functions as storage for downstream units

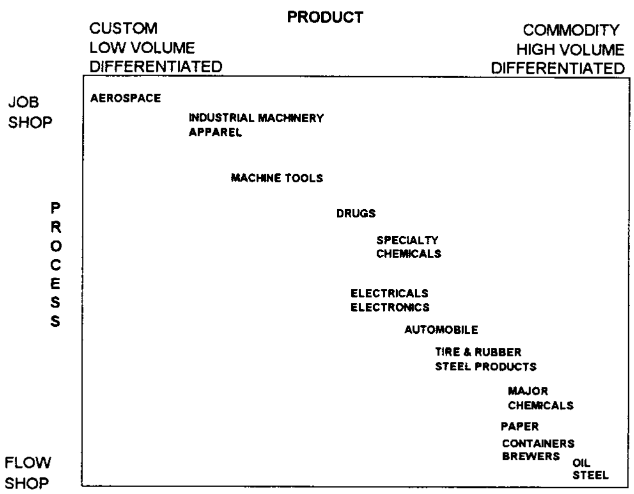

FIGURE 1: Product-process matrix [5]

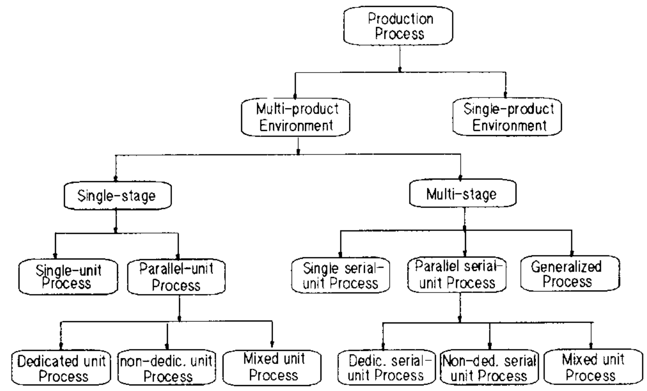

FIGURE 2: Classification of chemical companies by process structure

TABLE 1: Differences between Process Industries and Discrete Industries

	Process Industries	*Discrete Industries*
Relationship with the market		
Product type	Commodity	Custom
Product assortment	Narrow	Broad
Demand per product	High	Low
Cost per product	Low	High
Order winners	Price; delivery guarantee	Speed of delivery; product features
Transporting costs	High	Low
New products	Few	Many
The production process		
Routings	Fixed	Variable
Layout	By product	By function
Flexibility	Low	High
Production equipment	Specialized	Universal
Labor intensity	Low	High
Capital intensity	High	Low
Changeover times	High	Low
Work in process	Low	High
Volumes	High	Low
Quality		
Environmental demands	Yes	Hardly
Danger	Sometimes	Almost never
Quality measurement	Sometimes long	Short
Planning and control		
Production	To stock	To order
Long-term planning	Capacity	Product design
Short-term planning	Utilization capacity	Utilization personnel
Starting point planning	Availability capacity	Availability material
Material flow	Divergent + convergent	Convergent
Yield variability	Sometimes high	Mostly low
'Explosion' via	Recipes	Bill of material
By and co-products	Sometimes	Not
Lot tracing	Mostly necessary	Mostly not necessary

- Unstable product where a batch must be transferred immediately to the unit processor
- A mix of the above.

COMPUTER-INTEGRATED MANUFACTURING

Computer-integrated manufacturing helps a company to work more flexibly and efficiently in today's global market through integration of organization, planning, and control within all business functions. More specifically, benefits often mentioned when implementing CIM are increased flexibility, improved quality, reduction in inventory, reduction in space needed, shorter lead times, and increased productivity. Computer integrated manufacturing is well described as:

> The computer assisted integration of the production process and operations control functions needed for optimal deployment and productive use of the minimum manufacturing and management resources required to meet specific strategic business objectives[10].

CIM can be pictured as an umbrella that covers the technologies listed in Table 2. Technologies related to CIM are divided into three groups. The first group contains management techniques and technologies that support the integration of the company's functional departments. The second group of technologies support the shop floor activities by designing, planning, and controlling the process and products. The third group are computer-based technologies that are used directly on the shop floor for the production, handling, and transport of parts and products. It is outside the scope of this article to discuss all these technologies in detail. We refer to [2, 3, 4, 13] for a more detailed discussion of these topics.

Many of these technologies are already commonly used in assembly plants. However, implementation of all or some of the new technologies does not automatically result in a CIM company as viewed in this article. Only when the integration aspect is emphasized, is CIM viewed as a systematic, strategic approach for improving the overall competitive position of the firm by using computer-based technology as its vehicle.

We now turn to a number of focal points that should be considered when implementing CIM in the chemical industry. These focal points were derived after comparison of CIM literature within the discrete industries with well-known characteristics of the chemical industries. Emphasis is placed on the manufacturing context, as systems outside production, like sales-order administration and financial planning, are not markedly different from those used in discrete manufacturing, and are therefore not elaborated on. Discussion of these crucial factors is presented at the operational, tactical, and strategic level, respectively [7].

FOCAL POINTS

Operational Level

CIM should support process data acquisition (from the computer process control system) for use in business system applications like, for example, the use of throughput rates, downtime status, and inventory levels in the production scheduling department, or the use of electricity and fuel consumption to improve product costing.

There should be software for laboratory information management, which allows easy collection, storage, and retrieval of all test results. These packages should provide statistical process control (SPC) charts for use

TABLE 2: CIM Technologies

Group 1	*Group 2*	*Group 3*
Material Requirements Planning (MRP) Manufacturing Resources Planning (MRP II) Just In Time (JIT)	Computer-Aided Design (CAD) Computer-Aided Design and Drafting (CADD) Computer-Aided Engineering (CAE)	Robots Machine Vision Numerically Controlled Machine Tools
Group Technology (GT)	Computer Process Control	Flexible Manufacturing Systems (FMS)
Artificial Intelligence (AI)	Computer-Aided Process Planning (CAPP)	Automated Materials Handling (AMH)
Electronic Data Interchange (EDI)		Automated Transport Systems Automated Storage and Retrieval Systems (AS/RS)

by production personnel and statistical quality control (SQC) charts and certificates of analysis for customers.

Software to perform lot tracing and yield tracking should be integrated within the CIM system, especially with quality control and production planning.

Tactical Level

CIM should support efficient utilization of processing facilities while meeting customer needs. This includes specialized software in the following areas:

- Order processing software to perform product inventory checking. In addition, the software should track production commitments against capacity targets to provide immediate feedback on delivery dates to customers.
- Production planning software (CAPP) should take into account the fact that capacity should be scheduled *before* material is ordered (capacity-driven planning). This software should also incorporate the recipes that are used in the chemical industry instead of the straightforward bill of material. Complex dependencies in these recipes include the occurrence of co-products, by-products, quality-dependent amounts of input, and non-linear production structures (the amount of output is not a linear function of the amount of input). Because of the lack of a clear prediction of the quality of the output, which is contingent on uncertain conditions as pressure and temperature, production planning packages must deal with the situation that a product of other quality as planned may be produced. Planning also needs to deal with time restrictions that arise from perishable materials.
- Production scheduling software should be available to generate optimal (or near-optimal) schedules by minimizing setup times and grade changes subject to capacity constraints, in-process inventory capacities, and customer demand. Options include mathematical programming approaches, finite capacity loading routines, and manufacturing simulation software.
- Maintenance management software is needed to support the preventive maintenance function. This should be linked to production planning.

CIM should focus on supporting controlled blending of highly variable feedstocks. Increasingly, customers are redefining quality as "minimum variation from target." Today's customers are demanding that suppliers give proof of stable, controlled processes before purchase agreements are made. Mathematical programming approaches that integrate inventory information and laboratory results are needed to select highly consistent blends.

Strategic Level

CIM should integrate the different facilities of a company (if there is more than one) that are located at different sites.

Because most chemical companies already have a large degree of automation, the task of CIM is to integrate all the computer applications that are present.

Focusing on the different computer applications (see Table 2) that can be used to support CIM in the chemical processing industry, a case-by-case evaluation is called for. Standard MRP packages are hard to implement in the chemical industry because of the specificity of the industry, like the focus on capacity planning, the occurrence of by-products and co-products, variable yields, alternative routes, and the occurrence of waste products. Group technology, flexible manufacturing systems, and numerically controlled machine tools are only suitable when a large variety of complex parts or products are made in small to medium batch sizes, none of which applies to chemical companies. Machine vision for inspection or part identification is not possible when chemicals are being made, because the production process itself is "hidden." Other technologies, like Just-in-Time (JIT), computer-aided design (CAD), and artificial intelligence (AI), can be of great use to the chemical processing firms, although not in the same fields of application as in the discrete industry. Chemical firms can gain a lot from JIT, although they should focus primarily on the quality aspect of this philosophy. CAD in the process industries is used for process-plant design, facilities management, and plant maintenance functions. AI and expert systems can be used in fault diagnosis and inspection.

CASES

The above-mentioned findings were confirmed in a survey of six leading chemical firms located in the Netherlands and Belgium. A survey and personal interviews were conducted with automation managers of the six firms. The managers were confronted with questions regarding the production process, production management, automation, and the company in general.

The first company visited was BASF, a company which employs 140 people and manufactures propathene. It has a yearly capacity of 150,000 tons. Propathene is used in the production of carpets, car bumpers, injection needles, and garden furniture. The second visit was to the chemical and fertilizer division of the international chemicals group DSM. The division employs 2,700 people and produces three types of products: caprolactam, used in yarns, fibers, and plastics; melamine for thermosetting resins; adhesives and flame retardants; and six kinds of fertilizers. The third company, Fuji Photo Film B.V. Tilburg, is the largest establishment of the Fuji concern outside Japan, with 1,300 employees, and manufactures photographic paper, color films, and offset plates. The fourth concern to be interviewed, General Electric Plastics, employs about 1,600 people and produces granulated engineering plastics. Next was Bayer in Antwerp, Belgium. This company makes products like glassfibers and has 2,757 people on the payroll. The last company visited was Procter & Gamble in Brussels, producer of a larger variety of consumer goods.

The first five of the above-mentioned companies are typical examples of process industries: they manufacture commodity goods, in large volumes, with low production costs. The production process is characterized by expensive specialized equipment, oriented in one to three production lines, which operate around the clock. Production processes are mostly continuous, with little or no intermediate buffers and can therefore be categorized under multistage parallel serial-unit systems (see Figure 2). The exception is the chemical firm from Brussels, which manufactures a large variety of products, mostly in batch.

Trends like growing numbers of product varieties, custom-made products, shorter and more reliable throughput times, and guaranteed delivery times are becoming increasingly important, as most of these companies have changed in the years from a make-to-stock to a make-to-order environment.

Capacity is, as expected, the most important factor in planning, and emphasis is therefore placed on long-term planning. The use of computer applications is minimal, at least in the planning department. The production process, on the other hand, is highly automated. Planning systems are MRP-like systems that are used together with a manual system. Maintenance is seen as a necessary evil, and is not integrated with production planning. Other critical parts of production management, however, are the continuous monitoring of capacities of different production resources and the mixing of chemicals. It is imperative that the above-mentioned functions should first be thoroughly analyzed and put into a structured planning and control system before integration with other parts of the company can be considered.

The level of automation differed among the six companies, as is shown in Table 3. All computer applications were found as "islands of automation." The widespread use of electronic data interchange (EDI) is striking.

TABLE 3: Summary of Computer-Aided Technologies Implemented

	BASF	*DSM*	*FUJI*	*GEP*	*Bayer*	*P&G*
MRP/MRP II	X[4]	X[4]	X[4]			X
JIT						
GT						
AI	X			X[2]	X	
EDI	X	X		X	X	X
CAD/CADD/CAE	X	X	X	X	X	X
CPC	X	X	X	X	X	X
CAPP					X[3]	
Robots	X[1]		X		X	
Machine Vision			X			
NC Machines					X[1]	
FMS						
Automated Transport			X	X	X	X
Automated Storage			X	X		X

[1]: Only in the packaging department
[2]: In a very early stage of development
[3]: On a very small scale
[4]: Companies that have a planning system resembling MRP, without actual use of a commercial MRP package

The real issue, then, is the integration of these islands of automation. We refer to the manufacturing automation protocol (MAP) system, developed by General Motors [8], as a first start in this direction. Although their system is designed to link such systems as automated guided vehicle systems (AGVS), robots, and automated storage / retrieval systems (AS / RS) in a discrete manufacturing environment, it may prove applicable in the process industry as well. A more difficult problem is linking the different systems on a data level through a database management system. Islam and Batanov [6] concluded that there are still no database systems that are suited for a complex CIM system, and that more research is needed in this direction.

Our limited study furthermore indicated that, with the exception of General Electric Plastics, management in the companies investigated was not aware of the potential benefits of CIM, and no definite plans for integrating the various computer systems existed. The need for a greater awareness and more knowledge of the aims of CIM is apparent.

CONCLUSIONS

Characteristics of a process industry environment are compared to a discrete manufacturing setting within the framework of computer-integrated manufacturing. Adaptations to the strategic, tactical, and operational planning issues are discussed for the chemical industry example, before successful CIM implementation can take place. The results were derived from a limited survey of six large chemical firms in Europe, indicating the early, but promising, stage of CIM implementation in the process industry.

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