Process Industry
ERP Requirements
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Introduction

Meeting the Needs for Process Manufacturing

A process manufacturing company’s information system depends on data from every corner of the business: inventory receipts, quality assurance test results, payments for purchases, production records, customer orders, shipments and invoices, payments from customers, maintenance of equipment and facilities, investments, and taxes to name several. And, the information system must be designed to reflect the particular needs of a company’s business processes.

As distribution processes become streamlined, a shorter supply chain eventually pushes back into the manufacturing plant, with the assumption that the supply chain will be more responsive. Plant executives need systems to respond to that demand for shorter response times. Variable customer requirements, reduced inventory levels, ever-changing schedules and shorter production runs also impact plant operations – and necessitate the use of automation to ensure peak efficiency.

Moreover, with rapid innovations over the past few years, developments in automation and control have resulted in a drastic reduction in labor, and the widespread use of process control instruments. These developments have increased information flow between the plant floor and the ERP system.

Wonderware is the only company to provide industrial strength software to enable the immediate response needed—from sensor to supply chain. This enables the real-time, plant floor information to be the controlling in formation in a manufacturing environment, flowing upward into the business enterprise systems.

The focus is on the factory floor, specifically on the operator who is the most intelligent agent in a manufacturing environment. Automatic data capture provides real-time updates to your inventory, improving the speed, ease, and accuracy of data capture. Each operator is connected to all the information systems, to everyone else in the plant floor, and to all plant floors within the organization worldwide. This operations-centric manufacturing environment—where information is shared within and between plants and planning in real time – is truly the efficient supply chain.

It is critical that you consider production systems that can easily integrate to automatics data collection devices – for a system that is agile, adaptable, and easy to link.
Investing in information systems is a serious consideration. Once implemented your information system must serve the company for years to come. It must reflect how you do business today yet evolve through subsequent business practice changes.

The ROI on information systems is directly affected by three elements. These are the:

- initial cost to procure and implement
- ongoing cost of supporting the application and its technology
- ongoing costs to adapt to changes within the business.

Yet all three elements have a common critical success factor: How well does the application fit?

**The Evolution of ERP Systems**

Systems designed for the input, storage and retrieval of business information have evolved from materials planning systems called Materials Requirements Planning (MRP) to those that included more business processes known as Manufacturing Resource Planning (MRPII) systems. The name is now Enterprise Resource Planning (ERP) systems to suggest that all information systems required for the management of a manufacturing enterprise are part of the solution. The evolution of the name continues; one industry analyst group is using the name Enterprise Resource Management (ERM) systems. However, in protecting your ongoing ROI, the name is not as important as the design and scope of the information system.

**Evolution of ERP Systems Table**

<table>
<thead>
<tr>
<th></th>
<th>Materials explosion</th>
<th>Capacity, inventory, costing</th>
<th>Maintenance, quality, formulation</th>
<th>Financial consolidations, corporate level measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRP</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>MRPII</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>ERP</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>ERM</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
Originally business information systems for manufacturing companies were designed for discrete manufacturers, not process industries. These systems targeted industries such as automotive, consumer electronics, machine tools, etc. The discrete manufacturing sector produces piece parts to form sub-assemblies, which are then combined to form the final product. Nearly all ERP suppliers have built their information systems to support the business functions of discrete manufacturers.

In the late 1980s a few software vendors built systems specifically designed for process manufacturers such as chemical, pharmaceutical and food manufacturers. Process industries work with liquids, powders and gases, as opposed to piece parts. They deal with inconsistent raw materials, by-products, co-products and recycles, as well as yield variances, waste management and utilization—all factors that directly impact the bottom line.

Despite the differences between process and discrete manufacturing requirements, not every area of an ERP system has significantly different requirements. Financial application requirements do not differ between the two sectors in any significant way. (Wonderware Corporation considers product costing an operational function not a financial function.) Logistics is somewhat different depending upon the form of the final process product: Is it still a liquid? Is it shipped in bulk? Is it hazardous? Does quality change from one lot to another? In maintenance management there are some differences, but these are more in terminology than anything else. It is in the area of planning, controlling and measuring the manufacturing side of the business where information needs are fundamentally different.

**What’s In This Guide?**
This guide examines the unique requirements for the chemical industry focusing primarily on manufacturing information requirements. The purpose of this is to help you understand three things. These are:

- the requirements themselves
- the positive impact of a good ERP fit and
- the negative impact of a poor ERP fit.

This guide has five sections describing the critical requirements for chemical manufacturers in each of the following areas:

I. Business Environment  
II. Inventory Management  
III. Process Modeling  
IV. Analysis, Controls and Measurements  
V. Planning
After a general description of requirements in each section, the requirements are summarized for easy reference. More in-depth information follows each summary.

**At the end of this guide are two important appendices:**

- Appendix A. Product Identification: Sample Business Processes
- Appendix B. Problems Using a Convergent Model for Divergent Processes

*These appendices are highly recommended for more information.*
I. Business Environment Requirements

Summary
At the highest level, a process industry ERP solution must reflect the business environment. The ability to meet individual requirements does not ensure that a system has an architecture designed to support the current needs of the industry as well as future trends.

The business environment requirements for a process industry ERP solution are:

A. **Support of Plants, Factories and Sites.** Designed for the multiple site environments in which business processes have steps that encompass more than one site.

B. **Support of Co- and By-Products and Recycles.** Accurately model the manufacturing processes without resorting to games and tricks

C. **Relevant Cost and Performance Analysis.** Present cost analysis information in the context of volume and mix of production for any period of time

D. **Ease of Use.** Designed for non-technical workers to use as a personal productivity tool

E. **Openness.** Supports integration to corporate level as well as Programmable Logic Controller (PLC) level system

*The following section describes each of these requirements in detail.*
A. Support of Plants, Factories and Sites

Trends in the industry for mergers, acquisitions and spin-offs mean most companies now have multiple production sites in different locations—sometimes different regions of the world—producing the same products. Currently, the industry is consolidating some of these facilities to reduce overall costs while providing for both the production of products beyond a local region and the supply of upstream products for specialty production at other facilities.

Plant, Factory and Site Support Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flexible Coordination of Site, Region, and Enterprise Requirements</strong></td>
<td>The plant level system must be configurable to run some business functions independently while other business functions are performed dependently and sequentially across multiple sites. For example, inventory transactions is an independent, site-level function. On the other hand, if one site produces materials for a downstream plant, the enterprise might elect to have production planning and scheduling performed for the division, the region or the enterprise.</td>
</tr>
<tr>
<td><strong>Support for Distributed Implementation</strong></td>
<td>There must be a way to distribute the implementation across multiple databases and multiple servers while still exchanging the information required to perform an enterprise-wide function. For example, cost of the same product from one site to another may be different because of local processing and material costs, but the consolidation of that product from multiple sites must reflect the weighted average cost.</td>
</tr>
<tr>
<td><strong>Separation of Physical and Financial Information Views</strong></td>
<td>The plant-level system must separate out the physical view of information from the financial view of the same information. The inventory records must reflect the physical facts of how much inventory is held in which locations throughout the site. However, in a complex production facility some inventory may be owned by one legal entity and other inventory owned by another. Furthermore, the divisional reporting requirements may present a need for information to be aggregated in yet another view.</td>
</tr>
<tr>
<td><strong>Intelligent Accommodation of New and Sold Plants</strong></td>
<td>The system must allow for a plant, when sold, to be easily extracted from the enterprise view of the data. Conversely, a new plant added to the division or company must be able to quickly be included in the information pool. Since the new plant will not necessarily have the same application software, there must be an open design anticipating exchange of information for specific business functions across heterogeneous systems.</td>
</tr>
</tbody>
</table>
B. Support for Multiple Outputs (Co-Products and By-Products)

In many respects the process industry is the opposite of a discrete manufacturer’s assembly business. Products such as chemicals and food are often “disassembled” and “reassembled”. For many processes this results in multiple outputs. In the meat industry, chicken disassembly is an example of an inverted Bill of Material. The outputs are commonly called co-products and/or by-products. While there are no universal definitions of these terms, it is generally true that co-products are desirable, planned, high-value prime products produced from the same process. By-products are typically less desirable, less valuable and are usually unavoidable products of the process. By-products overall do contribute value to the producer and are said to have positive Net Realizable Value (NRV). Waste products are by-products with negative Net Realizable Value (NRV) because they incur expenses to store, clean and dispose of them. Finally, one other unique output stream is the recycle stream which can be reused. It can be produced at one stage in the process and then re-introduced at a stage up-stream in the process.

In an optimized information system, the user must be able to identify multiple outputs as well as define where in the process these outputs occur. There are two reasons for this. One reason is to understand when in the process an output is produced and may be used in other processes. The second reason is to understand the cost of production. For example, if the by-product is produced after the first processing stage and the prime product produced after the third stage, then the by-product’s cost is obviously less than the prime product’s cost. The manufacturer must account for the production of a recycle stream in one stage and its consumption at another stage.

An optimized information system should allow a powerful modeling and measuring capability when managing and measuring by-product and co-product production. Since the raw materials in many processes come directly from nature, they are inherently inconsistent. These quality differences may cause a different ratio of by-products, co-products, wastes and recycles even though the processing parameters are constant. Conversely, the processing parameters may have to be altered to maintain the desired ratio. A more in depth discussion follows in Section III: Process Modeling. Multiple outputs also need to be managed in all business functions including forecasting, planning, scheduling, and costing as well as performance and statistical measurements. Because most ERP systems were originally developed for discrete manufacturing environments, co- and by-product functionality has to be “attached” to the standard system to support process requirements. The consequences of this kind of system adaptation are also discussed in the section on Process Modeling.
## Critical System Features for Multiple Outputs

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate Process Modeling</td>
<td>Ability to model the quantity and timing of the production of all outputs including co-products, by-products, waste, and recycles.</td>
</tr>
<tr>
<td>Flexible Costing Rules</td>
<td>Ability to define costing rules. Ability to manage both Net Realizable Valuations (NRV) for by-products that are sold and wastes that are disposed of, as well as the percentage distribution of production costs by processing stage.</td>
</tr>
<tr>
<td>Flexible Planning Rules</td>
<td>Ability to define planning rules, particularly the sequences in which products are planned. With co-products there may be a forecast and master schedule for some or all of the outputs. Demand for one co-product will result in the production of all others. This “driven quantity” will contribute toward satisfying the demand of the product’s own forecast and/or master schedule.</td>
</tr>
<tr>
<td>Yield Management</td>
<td>Accommodates yield of individual products as well as the measurement of ratios between some/all products as a fundamental measurement of performance.</td>
</tr>
<tr>
<td>Output Scheduling Support</td>
<td>Ability to schedule output at the date/time level if the output of one process stage feeds another process.</td>
</tr>
<tr>
<td>Direct and Theoretical Reporting of By-Products</td>
<td>Reporting of a by-product through direct means (data entry or electronic measurement from PLCs) or through theoretical calculations.</td>
</tr>
</tbody>
</table>
C. Cost and Performance Analysis

Understanding cost and performance is a critical success factor. In the past, production sites produced only a few products and these products had dedicated production equipment. Financial systems were sufficient for the straightforward calculation of product costs.

Today, process manufacturers have a proliferation of products. These products are produced using the same equipment or using existing processes downstream but at the same site. Because of the number of products now flowing through the same cost center, using financially-based cost systems to develop accurate, individual product costs is difficult, sometimes impossible. Furthermore, as multiple methods evolve for producing the same end item (whether in a sister plant or with newer technologies in an existing plant), the setting of standard costs must reflect a weighted average cost. This type of costing can only be done using an ERP system designed for the process environment. (See Section IV: Analysis, Controls and Measurements.)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Support for By-Product and Co-Product Costing</strong></td>
<td>By-product costing must allow percentage cost distribution at the manufacturing stage, and/or NRV including a negative NRV to reflect the ongoing cost of waste management. Co-product costing must allow percentage cost distribution.</td>
</tr>
<tr>
<td><strong>Multiple Types of Cost Analysis</strong></td>
<td>All costs must be able to be analyzed in the context of the volume of production through the facility as well as product mix.</td>
</tr>
<tr>
<td><strong>Detailed Variance Analysis</strong></td>
<td>Variance analysis must be able to isolate volume/mix variances from usage and efficiency variances.</td>
</tr>
<tr>
<td><strong>Costing for Yield Variances</strong></td>
<td>Yield variances must be reportable in terms of cost</td>
</tr>
<tr>
<td><strong>Detailed Cost Projections</strong></td>
<td>Cost projections must reflect the projected volumes of different processes producing the same end item(s).</td>
</tr>
</tbody>
</table>
**D. Ease of Use and Learning**

Today the worlds of high technology and low technology coexist. On one hand, modern and expensive process control systems are used to monitor and control manufacturing processes. On the other hand, manual procedures are used to document inventory movements, production yields, maintenance work, etc. Companies have power users in the front office willing to take on any new technology, as well as workers who have contemplated quitting rather than putting their fingers onto keyboards. A system must be capable of supporting all types of users within the enterprise and be easy to learn and use for people at all levels of technical skill.

The key to a successful information system for top management is that the fundamental data entered throughout the operation be accurate and timely. Ease of use (and ease of learning) is a critical success factor in getting buy-in from every worker that this is “their system” and not “accounting’s system”. With today’s technologies, users can have their own workspaces on their monitors with their own icons and even individualized data entry screens.

A significant portion of the total cost of ownership is in the high cost of moving to new release levels sometimes referred to as “Release Liability.” Advanced technologies and modern designs fully support the retention of individual workspaces through error corrections and release-level migrations.

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**Ease of Use/Ease of Training Table**

<table>
<thead>
<tr>
<th>User Type</th>
<th>Number of Transactions</th>
<th>Access to Information</th>
<th>Driver of User Friendly Definition</th>
<th>Learning Style</th>
<th>Access to System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power User</td>
<td>1000/day</td>
<td>Multiple window, multi-layer, multi-facetted search for answers to complex questions</td>
<td>Speed of input and output; links between information in different parts of system</td>
<td>Willing to sit in classroom training; layered learning style; will build one skill upon others learned; comfortable with use of technology</td>
<td>Hourly; repeated use of system over time; access to many different areas of information system</td>
</tr>
<tr>
<td>Non-technical User</td>
<td>10 – 20/day</td>
<td>Single question or single route to answer question</td>
<td>Input of single data type; low volume; may be days between use of system</td>
<td>No training required; intuitive in order to learn by doing</td>
<td>Limited to specific areas of information system</td>
</tr>
</tbody>
</table>
**E. Openness**

There are many reasons why system openness is a basic requirement for any chemical system. One of the most important reasons is the need to quickly begin exchanging information with new sites added to the company or division. This is particularly true if a company has implemented any enterprise business workflow (centralized purchasing, for example) in which case the company needs to include new sites as soon as possible. Because newly acquired businesses are unlikely to have the same software as the acquiring company, the overall enterprise must find ways to operate productively in this heterogeneous environment. In an extended enterprise even if all sites have the same applications it is unreasonable to expect that they will all be on the same release level. Having ERP applications that have anticipated this type of environment is invaluable.

The ideal of a corporation having a single vendor solution for their entire enterprise is not realistic. There will always be other systems that need to be integrated and are not supplied by the primary vendor. There will always be legacy systems or components of legacy systems that will remain in place because they are working, they are not yet fully depreciated, or there are no resources for a project team chartered with replacing them. And, in the world of mergers, acquisitions and spin offs there will always be at least one site without the corporate standard software which must exchange information in support of enterprise-wide business processes. Open ERP systems which form the backbone of the total information system will be the only realistic answer.

---

### Critical System Features for Openness

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Easy Integration of Process Control and Site-Level Applications</strong></td>
<td>The ERP system architecture must support easy information flow to and from process control instrumentation as well as other site-level systems including quality management, route planning, maintenance, safety and training systems.</td>
</tr>
<tr>
<td><strong>Easy Integration of Plant-Operations Applications with Enterprise (Corporate Level) Backbone Applications</strong></td>
<td>The exchange of information between sites as well as between sites and HQ is essential for smooth, timely operations in corporations where financial consolidations are done at division and corporate levels and where business process steps occur across multiple sites.</td>
</tr>
</tbody>
</table>
II. Inventory Management Requirements

Summary

In the area of Inventory Management, the unique characteristics of raw materials in the process industry place special demands on ERP systems. Inventory Management differs radically from discrete manufacturing. The major areas of difference include how inconsistent raw materials and multiple streams of product output are combined, measured, stored, transported, evaluated and even identified.

The key Inventory Management requirements for a process manufacturer ERP solution are:

A. **Units of Measure.** Any unit of measure at any time. Conversion. Dual UOM (potency, catchweight, strength). Site specific.

B. **Units.** Inventory management by container ID (pallets, cases, etc.), including the management of transportation for hazardous goods.

C. **Lots and Sub-lots.** Quality tracking at the sub-lot level in support of fluctuating quality results through a total campaign of production.

D. **Identification of Products.** Need to view chemical, quality-related and physical properties of a product (e.g., quality attributes, container type) without changing item numbers for each permutation and combination.

E. **Status of Materials.** System prevents the usage or sale of materials not yet approved by quality assurance.

F. **Concentration.** Support for formulations and inventory control by the concentration (active ingredients) of a material.

G. **Catchweight.** Support for inventory tracking in two units of measure. This includes the ability to value, inquire, reserve, allocate, plan, produce, order, price, ship and invoice by catchweight.

H. **Shelf Life Control.** Support for expiration, retest, and user-definable “useful life” dates.

I. **Safety Issues.** Support for Hazard Analysis and Critical Control Points (HACCP) for analyzing production or product handling processes to detect hazards and risks of contamination within those processes. Support for hazardous goods documentation and safety monitoring systems.

J. **Consignment.** Support for inventory consigned to customer locations.
K. Tolls, Exchanges and Swaps  Support for unique chemical industry “co-opetition” practices.

The following section explores each of these requirements in detail.

A. Units of Measure
The process industry requires specialized functions in support of the many Unit of Measure (UOM) variations. The UOM can be in virtually any form: mass such as tons and grams, volume such as cubic-meter, liters, as well as the “discrete” units of measure such as “eaches”, and containers such as drums, tote bags, rail cars. In discrete manufacturing the UOM can never be reported as a fraction. While logical in the discrete manufacturing world because it deals with components, this limitation is a calamity for process manufacturing.

But the UOM problem for the process industry does not stop here. The UOM used by accounting to report the value of inventory held, may not be the UOM that is physically measured during receipt. The UOM used to develop the formulations may not be the UOM that is used on the scaled-up batch sheets. And, of course, customers and suppliers may not use the company’s UOMs at all. To further complicate matters these UOMs may be different within the same company at different geographic sites such as English UOMs in the United States and metric UOMs in Europe or Asia.

B. Units
A unit is a storage device that is transportable and can change locations. Drums, totes and pallets are examples of units; tanks and silos are specifically excluded. Not only can a unit change locations, but the contents of a unit can change over time. The change can be a change in quantity (based upon receipts and issues), or it may be a change in items stored in or on that unit.

A container (unit) in inventory may not be full. Therefore, there is a need to track fractional quantities, such as three-quarters of a drum. Furthermore, the so-called accounting (or valuation) UOM is not necessarily equal to the unit. In our example, three-quarters of a drum may translate into 48 gallons of item A or 87 kilos of item B. A container might become contaminated by an item stored in it and therefore become ineligible for storing any other items (or any items not within that product family). In some instances, cleaning the container can make it eligible for storage again. Such functions are never part of a discrete manufacturing ERP system.

If the unit is a pallet, there needs to be support for the tracking of multiple products stored on that one unit. For example, one pallet may have 20 cases, all of item A. The next pallet may also have 20 cases, 15 of item A and 5 of item B. This information must be tracked under the identification (ID) number...
of the unit. If the ID can track all information about the materials stored on or in that unit (including items, quantities, lot and sub-lot numbers), it simplifies all transactions for the ERP system. It also makes support for the bar coding of transactions such as receipts, issues, quality hold/release, shipments, transfers, etc. much easier.

C. Lots and Sub-Lots
Lot control is fundamental in the process industry because of quality differences in raw materials, intermediates, and finished goods. In a batch operation, the tracking of lots into and out of production is straightforward. Everything can be tied to the batch number. In a continuous flow operation, however, even the definition of a lot varies. Often a lot is arbitrarily assigned to production for a shift or for a day. But because there are fluctuations in the quality of the output over that time period in some chemical processes, there is also a need for the lot to be sub-divided into sub-lots. A sub-lot might identify production from one sample to the next, or it might identify a range of unit (container) IDs whose samples are combined to produce an average quality result.

To address these needs an ERP system must, at a minimum, support the following lot and sub-lot information:

- **Lot definition, lot numbering rules.** Each company (and sometimes each site) has their own conventions for lot numbering. Typically these are complex numbering schemes intended to provide embedded information in the code (for example, site/shift of production). These schemes may vary by type of material, raw material vs. finished product, or by product status, standard vs. R&D trial. A company’s conventions must be supported to provide consistency to workers and customers. Typical discrete-based ERP systems with lot tracing and tracking do not provide this type of support.

- **Splitting of lots into sub-lots.** Quality—the chemical and physical properties—may fluctuate over time during production. This is especially true for campaign production in which long, continuous production runs cover differing climatic conditions as well as fluctuations in raw material quality. In batching operations running consecutive batches, operations may wish to assign a lot number to indicate the production run, and sub-lots to track the quality from time to time or batch to batch. This assists them in tying back specific quality attributes to operating parameters tracked in the MES systems.

- **Lot Tracking (Where Used).** Whenever and wherever a material is input into the process, the quality of that input may affect the quality and attributes of the output(s). In order to track back through the process to find causal relationships, the tracking of all input lots is required. The information system should be able to track not only the use of the lot in
further production, but all transactions which affect that lot, such as changes in locations and changes in quality status.

- **Lot Tracing (Where From).** The converse of lot tracking, tracing is used to determine where a given output came from. Lot tracing ties back to all input materials, as well as production schedules. Dates and times must be part of the tracing process. This allows the cross-referencing to processing parameters as stored in the MES systems.

- **Physical or chemical attributes and characteristics of a lot.** Knowing the Where From and the Where Used of any given lot is just the beginning of the investigation. Information about the chemical and physical properties of the lot must be tied to each lot at each stage of storage, quality assurance testing and production. Which characteristics are tracked and reported is dependent upon the raw materials being purchased and items produced.

- **Lot/sub-lots in and on storage units.** To facilitate electronic feeds of information, the system must be able to drive transactions at the lot/sub-lot level when fed only the storage unit ID.

- **Rules for mixing lots and sub-lots.** When a new production run is sent into storage there are many rules which apply. Can lots be combined? If so, what is the new lot/sub-lot number? What are the new chemical, quality-related and physical properties of the combined lot? The system should allow the user to dictate their material management policies as well as maintaining the lot tracking and tracing chain.

- **Rules and restrictions for the storage of lots/sub-lots.** Whether lots can be combined or not, there are also rules about where lots can be stored (e.g., which vats in the brewery) as well as what kinds of containers the product can be stored in (e.g., product A can be stored in 55 gallon drums, but nothing larger, whereas product B may be stored in any sized container).

- **Forwarding lot number of the critical semi-finished goods to the final end product.** In many operations a lot number is assigned to an intermediate early in the multi-stage process and must be maintained through produced intermediates or finished products. When packing bulk intermediates (e.g. fruit juice, oil, etc.) into cartons, you may wish to use the lot number of the intermediate as the lot number of the finished product. A discrete ERP system will not have such a concept.

- **Control of usage and/or sale of lot and sub-lot.** Control must happen at two levels. First we must know if the quality assurance personnel has released the lot/sub-lot for use or sale. Secondly we must know if the specification is sufficient for use in a particular application. For example, a lower grade may be used when producing X but not when produced Q. Also, the quality parameters must be compared to those acceptable to the customer in a “sell-to-specification” business.
D. Product Identification

In discrete manufacturing the rule for product identification is “fit, form, function”. If the fit, form, or function of the item changes in any way, there is a new product code (item number) assigned. This item number then becomes the key to accessing all information within a discrete manufacturing database: how to make the product, how to cost the product, its customers, its pricing, etc.

In process manufacturing, the same formulation or recipe may result in products of differing quality or grades from one production run to the next. Because even slight changes in quality attributes can affect the performance for different end uses. Therefore customers often order a product and state their preferred specifications. It is critical to track the quality attributes of a product to serve the customer well. If each variant had to have a different item number (as it would using discrete ERP software) then the “item master” would quickly become unmanageable and customers would be faced with a confusing array of “items” to choose from when ordering.

What’s more, quality attributes must be tracked over time. For some materials, the storage conditions and length of time in storage will change specific attributes (for example, the clarity of glycerin or the maturation of cheese). Periodic sampling of the lot determines if any of the quality parameters have changed. If this required a change in the item number on the label at the warehouse, this would mean huge volumes of non-value added work.

With some processes, the purchased and produced items go to storage before the final results on all quality tests become available. In traditional ERP systems the transaction can’t be performed until you have the item number. Therefore, a company using such a system would have seriously delays in reporting production. All analysis of yield and cost of production would have to be delayed until quality results were known, the right item number selected, and the transaction completed. A process ERP system allows the receipt of the production, followed up at a later date by the quality control department to determine and specify quality attributes such as % fat, % solids, brix, acidity, grade, clarity, viscosity, taste, etc.

For some production, incoming raw materials with differing quality attributes can be used, but then the process and/or the formulation must be altered slightly. If a completely different model of production was needed for each combination of input change, process change, and compensating ingredient change, then the size of the “item master” would again become unmanageable. Furthermore, some end items can not be made cost effectively if the feedstocks do not meet certain specifications. Being able to select the proper input lots can directly improve yields and profitability.

In the process industry the answer for product identification is an item number (product code) that refers to the generic product with the ability to identify qualifying characteristics. In this way, the item number reflects the quality
parameters important to each business. Each lot is identified with the appropriate values for each characteristic as determined by quality testing, etc.

The key to all information within the system is then the product code plus the characteristic values for each critical quality attribute. This information is tracked at the lot/sub-lot level. With this information the user can access all necessary information and answer relevant questions. How much inventory of a particular specification is in stock? What is the master formulation? How did we make this particular lot? What should it have cost us? What did it cost us? What is its selling price?

This level of control on both input and output of quality specifications is key to many producers’ competitiveness. See Appendix A: Product Identification: Sample Business Processes for examples of various situations.

E. Status of Materials
The status of materials defines the rules of materials management. Classifying materials codifies materials management policies. For examples: Are certain raw materials quarantined upon receipt until tested? Can this material be sold? Used in production? Transferred to a remote terminal but not sold until quarantine has elapsed? Held for retest? Set aside for blend off? Such classifications are managed in traditional systems by moving the materials to specific locations within the warehouse (e.g., inspection) or to different virtual warehouses to “hide” the material from the MRP logic. However, the classification of the materials must be managed separately from the tracking of the physical location.

F. Concentration
Although potency or concentration is another quality attribute, it is generally more significant in understanding the use of the product. One of the reasons is that formulations often call for \( n \) active units of a specific ingredient, rather than \( y \) physical units. This supports the usage of different lots with variable concentrations (with adjustments to the physical quantity of the ingredient and, often, adjustments to other ingredients).

The most effective approach for handling concentrations is to support two parallel UOMs. For example, the first UOM (volume or weight) is tracked for purposes of reporting physical quantities on hand and inputting quantities to a specific process. The second UOM (concentration) is tracked for purposes of calculating physical quantities required in a specific formulation, as well as in determining purchase quantities and product costs. This type of design approach only exists in ERP systems intended for process manufacturing.
**Catchweight**

Catchweight is an absolute requirement in many food processing segments. It is not just the ability to capture and track inventory in two units of measure. It is also the ability to value, inquire, reserve, allocate, cost, plan, produce, order, price, ship and invoice by catchweight. Yet many BOM-based systems do not thoroughly support catchweight.

Two units of measure are required in industries such as meat, fish and diary processing in which the content quantity varies for each container. Catchweight is also called “variable weight” or “random weight” by some food companies.

The meat business requires that the exact weight (or volume, or quantity) of a material within a case or other container is captured and tracked. This exact quantity may differ from the standard quantity per case. This difference is caused by the nature of the product, packaging methods, or environmental effects upon the product. For example, a case of whole chickens may contain multiple chickens with an average case weight of 50 pounds. As the weight of each individual chicken may vary, the total case can weigh either over or under the standard case weight. Therefore, tracking one case out of inventory and then billing a customer for one case will not be accurate enough. To correctly value the inventory, as well as bill the customer accurately, it is necessary to also capture the total weight of the chickens within each case. The end result is that each case has its unique actual weight which rarely equals the standard weight. Therefore, a process ERP system must maintain and utilize inventory in both a case and a weight measure.
**G. Shelf Life Control**

Shelf life management requirements are well known in the food processing industry but are also a consideration for some segments of the chemical industry as well. The useful life of a product determines its efficacy for specific purposes. There is also a requirement to perform follow-up testing for specific quality attributes if goods have been in storage for an extended period of time. The system must therefore support the following dates.

**Shelf Life Control Requirements**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical Expiration Date</strong></td>
<td>This is the date after which this lot should no longer be used. It must be recognized by the system for related business processes: planning, scheduling, reservation for use in production, sales to specific customers. The logic must be “forward thinking”. For example, material that expires in two days cannot be reserved for a production order next week. Reclassification of the expired lots should be automatically done by the system to prevent errors on the part of the plant workers.</td>
</tr>
<tr>
<td><strong>Retest Date</strong></td>
<td>For products that age or change over time, an ERP solution should enable a re-testing process and be capable of defining a re-test date. This is a date by which specific quality tests must be conducted and the new quality results applied as new product characteristic values. The products may have to be temporarily “quarantined” until the re-tests are completed.</td>
</tr>
<tr>
<td><strong>User-Defined Dates</strong></td>
<td>Other date fields should be user-definable and available to trigger specific actions (such as, rotating drum stock) or be used in specific logic (such as guaranteeing customers “n” days of shelf life.)</td>
</tr>
</tbody>
</table>
H. Safety Issues

Safety is an issue that affects many process industry segments. Amid growing concern about the safety of the food industry, industry regulators are cracking down on sanitation and food safety requirements. **HACCP** (Hazard Analysis and Critical Control Points) is a system for analyzing production or product handling processes to detect hazards and risks of contamination within those processes. HACCP’s application covers the entire food production process, from the purchase of raw materials through end usage by the consumer. Food companies, in light of the vulnerability of their products to contamination, are under pressure to comply with HACCP standards and continually strive to improve quality/sanitation-control systems.

With the requirements of HACCP, it is becoming increasingly important to track information such as the chill temperature of raw materials during processing and storage. HACCP is plant specific and product specific, even line specific. HACCP plans must be developed for each process and each product. A process ERP system must provide the detail level information that supports these types of requirements.

In the chemical industry, safety issues are of a different type. Material Safety Data Sheets (MSDS) are multi-purpose documents used extensively in the chemical industry. They are of vital importance to three constituents: employees, customers, and those who transport goods. Because the MSDS can theoretically change with each formulation change, old revisions of the document left in circulation are a concern. Local regulations about what information appears on the MSDS and how it is formatted are another concern. An ERP system might provide MSDS functions tied to a formulation module, but this would not meet the requirements of all countries. Most chemical companies have existing functions that support the development, maintenance and distribution of MSDS region by region. The ERP system must be open enough to allow easy integration to existing systems. With new uses of the Internet and intranets, support for central repositories of MSDS information with remote access is very desirable.

The printing of Material Safety Data Sheets is only one portion of the transportation function within a chemical company. Planning for safe storage and transportation of hazardous goods places unique requirements on the information systems. The rules that govern the handling and transportation of hazardous goods are complex, subject to local regulations and change frequently. There are two main requirements in this area for an ERP system: the ability to monitor compliance (for example, what goods are planned to be shipped together on a single customer order) and the easy integration with existing transportation systems (for example, plan routes, order trucks and rail cars, track freight costs and so on.) The integration is bi-directional in that the transportation system requires specifics about the products and the ERP system requires specifics about the shipments.
### I. Consignment Inventory

ERP systems are evolving to provide information support for the total supply chain. Consignment inventory handling is one of the basic requirements for this. A streamlined supply chain strives to shorten the lead-time from purchase order to customer delivery as well as to drive all non-value-added activities out of that chain. One strategy is to agree with key customers to consign inventory to their location. This strategy assures them that they will have ready access to materials required for production or distribution. The supplier replenishes the inventory as it is used but has the advantage of not having to use valuable storage space. Another strategy is to agree with key suppliers to consign their inventory to your location. This assures you will have ready access to materials required for production or distribution. Again the supplier replenishes the inventory as it is used but has the advantage of not having to use valuable storage space. The following are important aspects of consignment inventory.

#### Consignment Inventory Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receiver of Inventory</strong></td>
<td>Chemical companies track supplier inventory in the same way they track their own inventory. However, supplier inventory is excluded from their internal inventory valuation. This means that the physical view of inventory must be separated from the financial view. The inventory is received but not owned. When the inventory is used, the ownership changes automatically. Depending upon the business arrangement, records may actually be exchanged (acknowledgment of receipt, notice of usage, invoice raised, monthly reconciliation), or there may be only a check sent to the supplier.</td>
</tr>
<tr>
<td><strong>Shipper of Inventory</strong></td>
<td>The inventory is shipped under a special order. The goods are shipped under pro-forma paperwork (including Bills of Lading, necessary MSDS and other legal documents), but no invoice is cut at this time. The inventory is still owned by the shipper and therefore needs to be tracked in their inventory records. The classification of this inventory, however, would prevent this inventory from being used by planning, scheduling or assumed available for other customer orders. Upon receipt of use, the inventory is depleted and the appropriate financial transaction completed.</td>
</tr>
</tbody>
</table>
### Summary Table for Consignment Inventory

<table>
<thead>
<tr>
<th></th>
<th>Owns inventory</th>
<th>Physically available</th>
<th>Inventory tracked in local system</th>
<th>Paperwork Required</th>
<th>Timing on change of ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receiver</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Purchase order; periodic reporting of inventory quantity; notification of usage; payment for materials</td>
<td>Upon issue to production</td>
</tr>
<tr>
<td><strong>Shipper</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Notification of shipment; reconciliation of reported inventory quantities</td>
<td>Upon issue to customer’s production</td>
</tr>
</tbody>
</table>

### J. Tolls, Exchanges, Swaps

A Company may decide to outsource processing of materials for a variety of reasons. This company contracts with a second processing company to perform this processing “service.” This practice is called tolling. Typically the materials to be processed are shipped in a consignment arrangement to the processor (toller), processed, and then shipped back to the contracting company. The contracting company owns all materials, feedstocks and end products, although both contracting and tolling companies must track the inventory. The tolling company is responsible for processing the materials in the specified manner and it is expected to achieve a specified resultant yield. Each company’s ERP system must support the material (inventory) and financial requirements of the tolling arrangement.
## Summary Table of Tolling Arrangement

<table>
<thead>
<tr>
<th></th>
<th>Owns inventory</th>
<th>Physically available</th>
<th>Inventory tracked in local system</th>
<th>Paperwork required</th>
<th>Timing on change of ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Toller</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Customer order for tolling service; periodic reporting of inventory quantity and production yields; notification of usage; invoice for processing charges</td>
<td>Never the property of toller</td>
</tr>
<tr>
<td><strong>Contract Chemical Company</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Purchase order for tolling services; notification of shipment; reconciliation of reported inventory quantities; payment for tolling charges</td>
<td>Always the property of the contactor</td>
</tr>
</tbody>
</table>

Exchanges can be much more complicated. In the simplest example, one producer has most production facilities on the East Coast but has customers on the West Coast. A competitor produces identical materials on the West Coast. In a special agreement, the West Coast competitor ships the required product to the East Coast’s customer saving the customer or the East Coast producer the freight costs. Coincidentally, the West Coast producer has customers on the East Coast and, in exchange, the East Coast producer supplies the identical product and product quantity to one of the West Coast producer’s customers. The products are packaged and labeled to the selling company’s specifications (not the producing company’s specifications) so the customer is typically unaware the selling company did not produce the goods and that an exchange has taken place.

More complicated exchanges may occur when equivalent, but not identical, products with differing values and differing quantities are involved. Both exchange partner’s ERP systems must provide the accounting and reconciliation
functionality to address the exchange requirements. Although a company may not have many of these agreements, they may be a key component of an overall product strategy. Hence, these arrangements need to be properly recorded in the ERP system.

### Summary Table for Exchanges

<table>
<thead>
<tr>
<th></th>
<th>Owns inventory</th>
<th>Physically available</th>
<th>Inventory tracked in local system</th>
<th>Paperwork Required</th>
<th>Timing on change of ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A (original need to fulfill order for Customer XX)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Customer order; notification to Company B; annotation of obligation for exchange – product code, quantity, date, etc.; invoice to customer XX</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Company B</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Exchange order (paperwork for shipment to customer XX); shipment notification to Co. A</td>
<td>Company B owns until shipment to Customer XX</td>
</tr>
</tbody>
</table>

*The specific requirements for exchanges include the following.*

For the selling company:

- Book the customer order, transmit order to partner and invoice without a physical shipment
- Track the item, quantity and value of each exchange order
- Reconcile and report monthly or quarterly (depending upon the contract requirements)
- For the producing company:
  - Book the exchange order
  - Produce and deliver goods to selling company specifications
  - Reconcile and report monthly or quarterly
III. Process Modeling Requirements

Summary
The process model for a process manufacturer is very different from the model used in the discrete industry. The poor fit of discrete manufacturing ERP systems for process manufacturing is most visible at the terminology level. The wrong terms can confuse end-users if they are fixed in the ERP software. For example, the term *Bill of Material* in discrete manufacturing might be replaced in process manufacturing by terms such as *recipe, specifications, formulation*, or *batch sheet*. Learning new terminology raises the level of resistance to a new system and presents unnecessary hurdles for initial, as well as ongoing, training of end users.

Manufacturing Terms Compared

<table>
<thead>
<tr>
<th>Process Manufacturing</th>
<th>Discrete Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recipe, Specifications, Formulation, Batch Sheet</td>
<td>Bill of Material</td>
</tr>
<tr>
<td>Specification, Batch Sheet</td>
<td>Routing</td>
</tr>
<tr>
<td>Lot Numbers</td>
<td>Serial Number</td>
</tr>
<tr>
<td>Material, Ingredients, Feedstocks</td>
<td>Items, Components</td>
</tr>
<tr>
<td>Bulk, Intermediates</td>
<td>Semi-finished Product, Sub-Assembly</td>
</tr>
<tr>
<td>Batch Size</td>
<td>Run Rate</td>
</tr>
<tr>
<td>Batches</td>
<td>Repetitive</td>
</tr>
<tr>
<td>Processing</td>
<td>Assembling</td>
</tr>
<tr>
<td>Campaigns</td>
<td>Production Run</td>
</tr>
<tr>
<td>Specification</td>
<td>Inspection Sheets</td>
</tr>
<tr>
<td>Quarantine</td>
<td>Inspection</td>
</tr>
<tr>
<td>Yields</td>
<td>Scrap rates</td>
</tr>
<tr>
<td>Process Control Systems, Manufacturing Execution Systems</td>
<td>CNC (computerized numerical control) Systems</td>
</tr>
<tr>
<td>Molecular Modeling</td>
<td>CAD (computer aided design) Drawing</td>
</tr>
</tbody>
</table>

But it is the difference in architecture of ERP systems that is far more important. Nowhere are the differences more pronounced in ERP systems than in the modeling of the manufacturing process itself. The reason is simple: process manufacturing uses a divergent process model that cannot be properly represented in ERP systems designed for convergent processes. (See the following section as well as *Appendix B: Problems Using a Convergent Model for Divergent Processes.*)
The Management requirements for a process ERP solution are:

A. **Co- and By-Products.** Direct modeling of by-products, co-products, recycles and waste.

B. **Costs.** Net Realizable Value (NRV) cost support for multiple outputs, as well as user defined cost distribution to multiple outputs.

C. **Master scheduling of any output.** The ability to translate forecasted demand into a stated master production schedule even when one process results in the production of two or more forecasted items.

D. **Multiple process definitions to produce the same end item(s) which fully support planning, scheduling and weighted average costing.**

E. **Direct assignment of usage and cost for non-material resources such as electricity, water, steam, etc.**

F. **Modeling of set-up, clean up and changeover times in support of proper scheduling rules and utilization analysis.**

The following section discusses each of these requirements.

**A. Co- and By-Products: Divergent Production**

The traditional bill-of-materials (BOM) model used in discrete companies assumes that a single end product is manufactured as in Figure 1. Many parts are assembled to make one item in what looks like the letter “A”. This is where the initial MRP architecture standard of keying all information to a single item number, the point of the “A”, originated. In food, pharmaceutical and chemical plants, many processes result in multiple outputs as in Figure 2 which looks more like an “X” structure. Take for example, a chicken disassembly process where the one chicken can produce 20-30 separate end products that can be sold or used for further processing. Another example is an oil refinery in which the raw material (crude oil) is refined into several types of product such as natural gas, rich oil, light cycle oil and decanted oil resembling a “V” structure. The manufacturing process is the inverse of the assembly/discrete manufacturing process (divergent vs. convergent.) The underlying architecture used to model such processes is also fundamentally different.
Another important issue in process modeling is that not all outputs are considered equal. The main difference is the market value of the output. Generally speaking outputs fall into one of two categories.

- **Co-Products**: These are valuable outputs of the manufacturing process. Because there is a market for these products, they are considered part of the core business of a chemical manufacturing company. Therefore, the business needs to develop detailed cost analyses (in order to understand margins on this part of the business), plan for them, manage customer demand for them, etc. They are viewed as distinct and separate products, but the processes that produce them are tied to other products. This must be modeled accurately.
- **By-Products:** These are unwanted outputs of the manufacturing process. Some have a meager market value while others have a cost of disposal. Some don’t meet co-product specification and need to be recycled through the process thus increasing their cost. Some are used as fuel or may be sold for minimal value and therefore have a credit value to the process that produced them. The information system requirements are the same for by-products as for co-products, however. The reason is that market demand for these by-products might change, or R&D may develop downstream processes to take the by-product and produce a value-added product.

Figure 3 shows an example of co-production with two output products, X and Y. If the chemical company has a BOM-based system, the representation of Y (assuming that X is a more important product) is problematic. BOMs can have only one output. One way to “fool” the system is to model Y with “negative consumption”. Figure 4 shows the BOM approach to modeling that both X and Y are produced from the process.

![Figure 3. Actual Structure](image1)

![Figure 4. Representation in a Bill of Material](image2)

Mathematically, this works for some parts of the ERP system. Consumption (a negative production) of a negative quantity will result in a positive. However, this trick has ramifications throughout the system itself and complicates the lives of everyone who uses the system.

The serious ramifications for this poor fit are these:

- Costs cannot be accurately modeled. Although Y can have a Net Realizable Value assigned to it, Y cannot then be costed in any other way as it is not a true produced item..

- Planning and scheduling activities cannot be properly modeled because the timing of when output occurs is unclear in the BOM. If you need to model Y being “produced” at a time other than the beginning of the process, you need to play another game with lead-time offsets. This offset is universal. If Y is produced after Stage 1 when making X, but after Stage 4 when making Q, the system cannot differentiate.
Consumption reporting/lot tracing is seriously compromised because transaction history shows a negative issue related to the production of a different product. Is this an adjustment or a receipt?

Batch, linear run times, and set up and clean up are critical to the Just In Time (JIT) planning and scheduling of the chemical facility.

The master file structure inherent to BOM models is fundamentally inappropriate for process manufacturing. For example, the recycling of Y is impossible with a BOM.

For detailed examples of these problems, see Appendix B: Problems Using a Convergent Manufacturing Model for Divergent Processes.

B. Direct Consumption of Electricity, Water, Steam, Waste, etc.
Chemical and food processes often require consumption of energy, water, steam, waste and so on be included in ERP processing models. These process components constitute significant manufacturing costs. (In the United States, the chemical industry is the single largest consumer of energy.) Moreover, energy—as well as these other costs—are likely to increase.

A process ERP system must fully support the modeling of all inputs, not just materials. A Bill of Material is designed to track only material inputs. Equipment and labor required to produce the end item are part of the routing. To include utilities or other miscellaneous resources requires more “fooling” the system.

A better approach is using a model that allows all inputs and outputs to be defined and tracked. This leads to more precise product cost projections and more accurate actual cost calculations. These types of expenses are directly assigned to production through the model, rather than being distributed en masse to production through overhead allocations. As product proliferation on site occurs in an effort to improve competitiveness, overhead allocation of energy costs becomes increasingly inaccurate and results in misleading information.

C. Modeling of Multiple Processes (Equipment, Material)
A BOM-based system assumes there is only one way to make a product. There can only be one BOM and one routing to define how things are made. These master definitions are used in planning and calculating projected costs.

In a plant, there are usually several ways to make a product. A change of process or formulation or recipe is commonplace. Changes in the quality of raw materials may require an alteration to the formula or process or both. Expansion of capacity at a production site can result in several production
lines—using both old and new technologies—to make the same end item. There are different cost profiles to each process—different yields, different run rates—as well as a need to plan and schedule different pieces of equipment to understand the projected capacity utilization. A process ERP system must allow for multiple models that can produce the same end item(s).

D. Process Instructions

Process instructions are vital in the process industry, much more than they are in discrete manufacturing. The “how” of assembly in discrete manufacturing is easily reverse-engineered, yet the components may be patented.

In contrast, the “how” of processing is the focus of patents. Process instructions are often the key to higher yields and better quality using the same material inputs as a competitor’s. It is no secret that crude oil is the base for all petrochemical products. But why is the lubricant of company A better than the lubricant of Company B? The key lies in the process instructions.

The secret might be a specific parameter held constant during the processing, or a specific technique in heating a mix. Often the secret is in the interaction of process steps and ingredients introduced sequentially into the process. To support consistent yields and quality, however, these process instructions must be communicated clearly to the operators.

Because a BOM-based system assumes that the materials listing is separate from the production steps (they are held in a separate file called the routing file), there are risks in correctly communicating nuances of processing to operators. In a chemical ERP modeling system, the process stages clearly show the sequence of each processing step and which inputs are introduced at each stage. This type of architecture allows modeling expertise—the manufacturing process—and enables improvements to product quality and overall competitiveness.

E. Batch Consumption (Non Linear Function of Usage)

Chemical, pharmaceutical, and food processing is done in vessels, reactors, mixers, tanks and so on. When planning and scheduling how long equipment is utilized, non-linear logic is required. Because assembly time calculations are always linear (10 minutes per piece, therefore, 60 minutes for six pieces), BOM-based systems may not have support for non-linear calculations.

For example, whether a 1000 kilo mixer is filled with 980 kg. or only with 720 kg. doesn’t matter from a planning or scheduling point of view. The mixer is occupied and the mixing time is one hour. However, if the quantity to be mixed is 1150 kg, the mixer has to be used for two hours. This non-linear
consumption must be considered in the planning, costing and manufacturing processes.

In order to make reasonable recommendations however, the logic also needs a sensitivity factor to determine when additional batches are required. To continue the example, the planning logic with a 10% sensitivity factor added would assume that 1025 kg. could be processed in one batch, but anything over 1100 kg (1000 kg + 1000 kg x 10%) would be two batches. Furthermore, there might be rules for minimum quantities because some reactions require a critical mass to work successfully. In such cases the system might plan two batches (1000 kg and 600 kg, assuming 600 kg is the minimum). The sensitivity factor and batch minimums work together to best model the process.

F. Set Up and Clean Up
Set-up and clean-up time factors are required in both the discrete and process industries. The difference in the software support, however, is with the sequencing of production to minimize changeover times. In some chemical processes moving from one product to another is done with minimal “twilight” or off-grade materials produced. However, radical shifts between products require a shut down and restart to avoid significant off-spec materials being produced. To maximize our productive utilization of capacity, preferred sequencing rules must be followed (for example, low pressure to high pressure, light to dark). The challenge here, however, is matching the customer’s required date to the preferred production date. Simulations of alternate sequencing can alert the schedulers to the cost of under-producing shippable product when sequencing rules are violated.
G. Calculations in Support of Production Processes

BOM-based systems introduced the concept of backflushing to avoid unnecessary transactions. For example, the system would remove 100 fasteners from inventory for every bicycle received off the end of the production line. However, in the process industry the calculation of consumption of ingredients (per the BOM) is not necessarily derived from the reported quantity of produced resources. Different drivers of these calculations are:

- The reporting of the quantity of raw material A used in charging a reaction can drive the theoretical calculation of X produced, as well as the time utilized on the equipment.
- The reporting of the quantity of raw material A used in charging a reaction while driving the theoretical calculation of X produced simultaneously drive the theoretical consumption of raw materials Y and Z.
- Through the reporting of 8 hours used on reactor 1, the system will theoretically calculate the production from that processing stage as well as the consumption of all raw materials.

The power of these calculations is that we can report the element(s) that are known to us most certainly and in the most timely fashion. The system derives the corresponding consumption and production even if the reported element is not a quantity of a produced item. The importance of the theoretical calculations is to quickly get to reasonably accurate numbers in support of other areas of the business such as customer service, inventory management and cost analysis. Of course, this calculation method will never detect any variances. Variances are visible under two conditions:

1. We specifically enter a transaction for consumption or production. This can be done affordably by extracting usage and production information from the process level control systems in place in the facility. If the accuracy of such measurements is suspect, then we can try the method in number 2 below.

2. We report, in aggregate, the usage of materials or steam, utilities and so on based upon daily tank readings or other measurements. Aggregate reporting prompts the system to find all theoretical usage of the resource in a given period of time and generate the necessary adjustments.
IV. Analysis, Controls, and Measurement Requirements

Summary
The process industry has historically focused on controls at the Control Room level and measurements at the financial level. With the advent of ERP systems designed for the chemical and food producer, controls and measurements can be more detailed, timely, accurate and useful. Improvements in modeling the process, as well as designs for the collection and use of production/quality data, have the potential to support complex decisions as never before.

The Analysis, Controls, and Measurement requirements for a process industry ERP solution are:

A. **Process Costing.** Full support for process costing, weighted average actual cost calculations as well as activity based costing. Cost analysis of actual performance as well as simulation of cost results under different scenarios.

B. **Data Gathering.** Electronic feeds of transactions from PLCs, load cells and bar-coding systems, and so on.

C. **Performance Measurements.** User defined equations for the calculations of significant performance measurements unique to each business.

The following section describes each of these requirements in detail.

A. Process Costing
All BOM-based systems assume that the cost of production needs only be reported as a job cost. As each machine tool is assembled the costs of materials, labor, and overhead are collected against the “job order”. Variance reporting against the projected standards is reported for the job. Since we may never make that same model of machine tool (with the same combination of options) again, this analysis can stand on its own.

In the process industry, one batch could be equated to one job. However, many of the same batches are made over a period of time. The cost of production for each individual batch as well as the cost of the product, as an average over a period of time, are required. The period of time may not equate to an accounting period. In order to serve the chemical industry an ERP system must be able to:

- Calculate and report on costs of each batch as well as the average actual costs (even with variations in formula and processes from batch to batch) and
- Report on the variances at the summary and detail levels
Requirements for overhead distribution are also significantly different for the process industry. Historically, discrete manufacturing has been very labor intensive and frequently the primary component of product cost has been labor. Discrete production overhead has been distributed or allocated based on this primary cost driver—labor hours. Overhead in the process industry cannot be distributed through labor hours. More importantly is the need to answer the question: When is overhead, as a distributed cost, going to result in accurate product costs and when is it more accurate to manage some overhead costs as assigned direct costs?

Energy is a good example of the allocation problem. Some products are energy-intensive and others are not. Overhead allocation of energy costs based on machine time, feedstock consumption or tons produced will result in misleading cost reporting. Products using high energy will be under-assigned costs for energy while low energy consumers will be over-allocated. The process model that includes energy as a consumable input enables direct assignment of energy costs to products in correct proportion. With theoretical consumption calculations of energy (per the model) and aggregate reporting of total consumption to adjust to an actual number on a shift or daily basis, the cost of energy is realistically assigned.

Not all overhead expenses should be part of the process model. Distributing overhead costs as they are in job costing systems—a static rate set once per year—does not meet process manufacturing needs. Rates set once per year will often mask the root cause of cost variances and postpone recognition of the problem and resolution.

Cost analysis for the process industry must support a sophisticated and rigorous calculation of costs. Because there is a very high proportion of fixed cost in the industry, cost analysis must be done in the context of volume and mix of products produced during a period. Additionally the system must isolate variances—the variances of volume fluctuations and product mix fluctuations from variances caused by processing issues such as yield fluctuations due to poor quality of materials. The period of time for this analysis can not be limited to the batch (job), nor to the financial period since campaign production may run over multiple periods and align with neither the beginning nor the end of a period. Furthermore, annual maintenance shutdown stops volume but not fixed expense. Therefore, calculation of costs should support the ability to recost all products produced to include their share of fixed costs during idle periods.

With the advent of global management, the rules for cost distribution are even more challenging. Local plants have to use their calculations for reporting of inventory valuation according to local rules. These plants must also report their costs to regions, divisions and/or corporate headquarters for comparison of plant-to-plant product costs. For this comparison to be valid, cost analyses must be calculated using the same allocation rules for overhead. It’s very unlikely to have top-to-bottom agreement on how to distribute overhead costs and still support all needs for the analysis of costs. Therefore, there must be a
system-supported ability to have a user drive their own cost analysis with their own rules and retain this profile of cost on the system in parallel with other cost analyses. This is far beyond the design of a job costing system.

One distinct advantage of cost analysis designed for process manufacturing is that it is not limited to just analyzing history. The same rules for distributing actual overhead over actual production can be used to distribute budgeted overhead over projected volume and mix of planned production. With simulation capabilities, the system can support all types of cost modeling for decision support. Critical decisions such as product abandonment, introduction of new products, changes in product mix, increasing capacity, decommissioning parts of plants, response to changes in prices and labor rates can then be addressed with comprehensive analysis and confidence.

B. Data Gathering

**Wonderware’s Sensor to Supply Chain Integration**

The sources of key information in a chemical manufacturing enterprise is on the factory floor. Process sensors, PLCs, operators, and other devices in the factory floor have the most up-to-date and, therefore, most accurate information essential to the global operations of the enterprise. Many ERP applications ignore this vital information and simply push the information down to the factory. *In the world of eCommerce it is often forgotten that while you may be able to purchase in seconds over the Internet, the manufacturer may not be able to truly respond for weeks. The chemical industry cannot eManufacture!* **Wonderware’s Sensor-to-Supply-Chain vision** signifies recognition of the importance of this information flow and the importance of employing it as a critical element in enterprise decisions. When customers call to determine the status of their orders, the information resides in plant floor systems. When suppliers call to determine if they can make a bulk delivery, the factory systems know the tank inventory level and whether the delivery will fit!

Wonderware’s integration of Factory Suite, the world’s first integrated, component-based MMI system, with Protean provides this critical bottoms-up integration of the enterprise. Factory Suite views, stores, collects and analyzes the information on the factory floor. Integrated to Factory Suite, Protean uses this information to perform production reporting, to perform inventory management tasks, to plan and schedule using up-to-the-minute information, to determine the costs of manufacture and much, much more!
C. Performance Measurements

A well-designed process ERP system opens up new kinds of performance measurements that have not been traditionally supported in BOM-based applications. The classic measurement of performance (other than cost) within the process industry is yield. Ironically, the calculation of yield is not a single calculation. For one company the yield might be measured as Tons In versus Tons Out. This raises some questions, though. Are all inputs part of the In total? Would you include catalysts or carrier solvents used to control the reaction? Would all Outs be a single total?

Yield can be thought of more appropriately as a ratio when the user can define the equation she/he controls, specifically—the Tons In/Tons Out calculation. Additionally, ratios allow the calculation of input feedstock per kilowatt-hour of electricity, or kilos of recycles per ton of finished product produced. You might find that tons produced per hour of reactor time and/or the ratio of two feedstocks to each other may be more indicative of process performance than a typical yield calculation.

Just as the cost analysis must span a user-defined period of time, so must all performance analysis. This ability for the system to report a ratio over a period of time and compare it to other ratios puts powerful analysis tools at the fingertips of operations personnel. For example, any calculated ratio can be compared to projected (standard) ratios as well as ratios for longer or shorter periods of time, or to ratios from one season to another (where ambient temperature can affect some process yields). If plant personnel can detect trends early enough to take corrective action, then yields and product costs can be controlled effectively.
V. Planning Requirements

Summary

There are many kinds of planning in a process business but within the scope of ERP, planning refers to the planning and scheduling of production. The first objective of planning systems is to determine, for the foreseeable future (days, weeks, months, one or two years), what capacity loads will be placed upon the production facilities. In some parts of the process industry, in which materials are on allocation or are seasonal, there may be a need to plan for material constraints as well. The purpose of this plan is threefold:

1. to have a picture of capacity utilization and some warning as to whether there is a capacity-constrained situation
2. to generate a proposed production schedule for the short term (typically one to four months into the future)
3. to generate a proposed purchasing plan for the procurement of feedstocks and other materials

In traditional planning systems Master Production Scheduling (MPS) was the highest level planning application. MPS systems looked at the supply of materials against forecasted demand, and reported projected capacity loads in so-called rough-cut planning reports. This level of detail is not sufficient for the capacity-constrained, sequence rule-based chemical producer. Furthermore, there are the following issues to be specifically addressed in a chemical ERP system:

A. Multi-Site Planning and Multi-Sourcing. In a global business, determining which of several sites will be best suited for meeting demand. Planning for transfer of goods from upstream plants including, when necessary, the inter-company sale of the goods

B. Lot Sizing Rules. Sensitivity to lot sizing rules (which compare to batch size limitations) in planning recommendations

C. Co-product and By-product Planning. User control over the sequencing in planning by item as well as by process model

D. Level by Level Planning. Interruption of the planning logic for finite scheduling and balancing against customer demand at the bottleneck points within the facility

E. Allocations and Reservations. Allocations and reservations of materials in stock as well as projected to be received from vendors or production

The following section describes each of these requirements in detail.
A. Multi-Site Planning and Multi-Sourcing

Over years, most chemical and food corporations have organized vertically to the point that some materials for one plant actually are produced in a sister plant. Whether that plant is next door or miles away, part of the same legal entity or a different one, the planning of production requires that this relationship be understood by the planning logic.

The system logic must encompass the differences of a sister plant relationship on pricing as well as ordering and receiving processes. For example, requests for transfer of goods from a sister plant may be electronically transmitted as a production demand rather than a customer order. Also, shipment of the goods may be governed by special materials management rules. For example, goods that have not had final QA analysis and release performed might be shipped to a sister plant; product in a similar status might not be shipped to a customer. Lead time is reduced with the understanding that the receiving sister plant will not use the goods until notified by the shipping QA personnel, or the goods will clear final QA approvals during transit. The receipt of the goods may require financial transactions other than to debit inventory in the receiving plant’s ledgers. The system must have enough “knowledge” to determine whether there will be an inter-company sale recorded because the shipping and receiving sites are in different legal entities.

B. Lot Sizing Rules

Lot sizing rules in planning parallel the physical and chemical constraints of the process. A manufacturing system should determine, through sensitivity factors described earlier, whether it makes sense to produce a new batch. For example, if the standard batch size is 34 tons, does it make sense to produce two batches when the demand is 35 tons? What is the minimum quantity required in a batch to be cost effective? What is the minimum quantity required to begin the reaction?

C. Co-Products and By-Product Planning

Whether there is an independent demand (a co-product) or there is a limitation on disposal or storage (a by-product), the user needs to be able to define the rules for master scheduling these items. Figures 5 and 6 show an example of two processes which produce two outputs each, with Z being produced from both processes. The quantities of X, Z, and W will be different when we plan different processes to meet the requirements in different sequences. Different sequences have different purposes such as to minimize inventory of a product due to cost, storage constraints, waste regulations, customer demand, capacity availability and so on.
For example, if independent demand is 600Z and 200X, then sequencing of planning (and selection of the processes to be planned) is significant. There are several alternatives:

**Sequence 1:** If planning for the production of X is done first using process X/Z then the 200X will produce 400Z. If process W/Z is used for the production of the balance of the Z requirement (to minimize the production of X) then an additional 200Z is produced (to meet the total requirement of 600Z) and 100W is produced.

**Sequence 2:** Planning Z first (and the X/Z process alone), then the quantities would be as follows: 600Z, as requested, and 300X with 0W as the W/Z process was not used.

**Sequence 3:** It gets more complicated when you try to optimize the inventory level of W at 150. The following planning logic would result: 150W creates 300Z. Because a total of 300Z is required and there is to be no more W produced, then the 300Z must be made using the XZ process, resulting in 150X. However, the total demand for X is 200.

Here is another decision point: Produce more X to meet the demand and hold additional Z in inventory? Or under-produce the X, and hold no excess inventory? The decision will be based on a myriad of business conditions. Therefore, the planning logic of the chemical ERP system must allow the user to dictate the sequencing rules in order to be manage the inventory levels which result.

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Sequence I</th>
<th>Sequence II</th>
<th>Sequence III</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>200</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>Z</td>
<td>600</td>
<td>600</td>
<td>700</td>
</tr>
<tr>
<td>W</td>
<td>100</td>
<td>0</td>
<td>150</td>
</tr>
</tbody>
</table>
D. Level by Level Planning

The process industry requires detailed capacity planning to simultaneously maximize the throughput on finite capacity, minimize changeover times, work within constraints of storage limitations, and meet customer demands. However, sequencing to maximize productive utilization rarely matches the sequencing of customer demand. If an ERP system builds the total plan through intermediates and raw materials before determining bottlenecks and other constraints, then the planning run results are often flawed. Many process companies turn to optimization logic to help with the more complex multi-constrained planning problems. However, there are other effective approaches.

The planning run logic in the process ERP system can be built to be interrupted at the levels in production where constraints and bottlenecks occur. The user can dictate where these interrupts happen in case the product mix in any one planning period changes causing a shift in the bottlenecks. The planning logic does all of the inventory netting, lot sizing and recommendations through to the level indicated. The planning run stops and the recommended production is finite forward loaded (according to the user’s sequencing rules to minimize changeovers). The results are then analyzed by the system to indicate any misses on customer order due dates. The scheduler can manipulate these. When these issues are resolved, the amended plan is turned back to the planning logic. It then plans for the downstream production of intermediates as well as the procurement of raw materials.

E. Allocations and Reservations

As process companies move to differentiate themselves on customer service, inventory management becomes a critical success factor. Reserving specific lots for customers to match their quality specification is just one example of the added functions required in a process ERP system. Knowing the net inventory position by date is also key in providing customers with information as well as in the production planning and scheduling cycle. The following are some special allocation and reservation requirements for the processor.

Quality Lead-Time--Quality testing lead-time influences when materials will be available for use or sale. If a series of tests requires 4 days for completion, then materials will not be “available” for use or sale on the date of production but rather 4 days later. This may be true for materials that are sold, materials that are purchased, or intermediates just produced. The quality classification of materials must carry the expected date of availability that the system can employ in its planning routines. This expected date is the date of importance for customer service representatives and production planners.

Reservations for Not Yet Inventoried Materials --Two requirements are important for companies reducing inventories on hand yet competing on customer service. These requirements are:
Reservation for a future expected receipt from a purchase order--
This kind of reservation is important in cases of extremely low inventory levels, very tight safety stocks or when materials are bought against specific quality specifications.

Reservation for a future expected production from a production order--This is important when producing intermediates for subsequent production orders or finished goods for customer orders. If in a capacity constrained situation, or where there is a strict sequencing of products produced during a campaign, assignment of customer orders to specific production runs is critical. This information must be visible to all customer service representatives so that they can avoid “double selling” of future production.

In a strategy to reduce on-hand inventories, a system which limits allocations and reservations to only stocks physically on hand is a detriment. Informal procedures (sticky notes, phone calls, emails) pleading to hold production from batch for a specific customer fail. System workarounds that “hide” the inventory defeat the planning system objectives. The ERP system, itself, must provide these controls.
VI. The Total Solution

Summary of Process Industry ERP Requirements

The differences in processing chemicals and food versus machining and assembling parts are obvious when touring various sites. It’s not surprising that the information systems to support such different businesses would have significant differences as well.

**Summary of Process Industry ERP Requirements**

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Detailed Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Business Environment</strong></td>
<td>Must support multiple site environment whose business processes have steps which encompass more than one site</td>
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<td></td>
<td>Accurately model the manufacturing processes without resorting to “tricking” the system</td>
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<td></td>
<td>Present cost analysis information in the context of volume and mix of production for any period of time</td>
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<td>Be intuitive enough for non-technical workers to use as a personal productivity tool, but robust enough for power users</td>
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<td></td>
<td>Be open to support integration at all levels from corporate systems to PLC systems</td>
</tr>
<tr>
<td><strong>Inventory Management</strong></td>
<td>Any unit of measure at any time</td>
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<td></td>
<td>Inventory management by container ID, including the management of transportation for hazardous goods</td>
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<td></td>
<td>Quality tracking at the sub-lot level in support of fluctuating quality results through a total campaign of production</td>
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<td></td>
<td>Visibility into qualifying attributes of a product (e.g., quality attributes, container) without changing item numbers for each permutation and combination</td>
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<td></td>
<td>System support which prevents the usage or sale of materials not yet approved by quality assurance</td>
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<td></td>
<td>Support for formulations and inventory control by the concentration (active ingredients) of a material</td>
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<td></td>
<td>Consignments, tolls, exchanges and swaps</td>
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<tr>
<td><strong>Process Modeling</strong></td>
<td>Direct modeling of by-products, co-products, recycles and waste</td>
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<tr>
<td></td>
<td>Net Realizable Value (NRV) support for multiple outputs, as well as user defined cost distribution to multiple outputs</td>
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<tr>
<td></td>
<td>Master scheduling of any output</td>
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<td></td>
<td>Multiple process definitions to produce the same end item(s), which are fully recognized in planning, scheduling and weighted average costing</td>
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<td></td>
<td>Direct assignment of usage and cost for resources such as electricity, water, steam, etc.</td>
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<tr>
<td></td>
<td>Modeling of set-up, clean-up and changeover times in support of proper scheduling rules and utilization analysis</td>
</tr>
<tr>
<td>Analysis, Controls and Measurement</td>
<td>Full support of process costing, weighted average actual cost calculations as well as activity based costing for actual costs, projected costs and “what if” analysis</td>
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<td></td>
<td>Electronic feed of transactions from PLCs, bar-coding systems, etc.</td>
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<tr>
<td></td>
<td>Aggregate reporting of total usage to a location (department or work center) to adjust theoretical usage and production numbers after tank readings are taken</td>
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<tr>
<td></td>
<td>User defined equations for the calculations of significant performance measurements unique to each business</td>
</tr>
<tr>
<td>Planning</td>
<td>Planning for transfer of goods from upstream plants including, when necessary, the inter-company sale of the goods</td>
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<td></td>
<td>Sensitivity to lot sizing rules in planning recommendations</td>
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<td></td>
<td>User control over the sequencing in planning by item as well as by process model</td>
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<td></td>
<td>Interruption of the planning logic for finite scheduling and balancing against customer demand at the bottleneck points within the facility</td>
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<tr>
<td></td>
<td>Allocations and reservations of materials in stock as well as anticipated to be received from vendors or production</td>
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</table>
Appendix A

Product Identification: Sample Business Processes

Material Management -- When lots are produced and stored, operators enter the lot identification (batch number) and the quantity produced. As quality test results are known, the lot gets its quality characteristics assigned. When all results are known, the lot is then classified as to its status: Available, Retest, BlendOff, etc. The characteristic values can determine the future use of the lot, can indicate the performance/yield of a specific batch run, can determine the selling price, etc. Lots can be combined (particularly when storing in tanks) and the quality attributes of each individual lot must be tracked, but the combined (calculated) attributes of the current mixed lot in storage must also be tracked.

Quality Management -- The Quality department reports results for specific lots or sub-lots as results are known, finally making disposition when all data is available. However, this partial information is available to others for their reporting of tons produced, and, in some instances, for matching to customer specifications where their requirements are not as broad as internal requirements.

Production – In trying to control the consistency of the output from production, selecting the best lots for input is critical in some processes. It is easier to control the assignment of lots to specific production runs by searching on specific attribute values which have previously been determined to be significant on the overall performance. Understanding the various quality attributes of the inputs will facilitate the tuning of both the process parameters and the formulations, resulting in improved yields and profitability.

Performance Analysis – In some processes the performance (run rates, yields, rate of recycles, and therefore costs) is determined by the quality attributes of the inputs into the process. Being able to see the attribute values for each input makes this analysis easier. Historical analysis comparing input/output attributes with processing parameters assists in continuous improvement programs.

Customer Order Management -- When a customer orders a specific quantity of product with their pre-defined specifications, chemical manufacturers must be able to deliver on that order. This is often called “Sell to Specification”. In the world of competing on customer service, we can not ask our customers to order different item numbers based upon their quality requirements. Nor can we run the risk of shipping product that does not meet their specifications. Having the customer order the “generic” product, and then to further qualify this with their required values for significant characteristics is the most straightforward method of facilitating this communication. Of course, we must be able to identify and track products with specific characteristics directing shipping personnel to the proper storage location of the required lot.
**Procurement** -- Procurement is the mirror image of customer order management. In order to improve our performance, we need to be able to order to our specifications. In some instances, we need to reorder additional materials and want to specify the same lot number as a previous shipment.

**Appendix B**

**Problems Using a Convergent Manufacturing Model for Divergent Processes**

It is apparent that putting something together (assembly or convergence) is the opposite of taking something apart (disassembly or divergence). So it may be obvious that information systems to support such opposite production methods would also have to be different. There are, in fact, two methods in software applications for the modeling of such processes: Bills of Materials with their attendant Routings and Production Models (US patent number 4,864,507).

We have seen that the BOM can be tricked into mathematically calculating a projected receipt by using a negative quantity for a requirement (a negative receipt—and, therefore, negative times a negative makes a positive). The mathematics is correct, however, this trick leads to other problems throughout the system in the management of the information. As these problems add up, and more tricks are played to get the answer to come out correctly, the software gets more and more complicated and finally reaches its limitations.

The production model is a model of a process. Whether you are assembling or disassembling the production model can reflect that in a very straightforward manner. In fact, as seen in Figure 3 shown earlier, this can be shown graphically and logically to all users. What, then, are the specific pitfalls for BOM (convergent) systems?

**Ease of Use**

Workers are used to physically managing and monitoring the materials and equipment in plants. They may have had no formal training in mathematics since high school. They might be reluctant to begin to use computers to track inventory, to report their activities, to review what production schedules are in front of them for the next few days. Having to learn tricks to get the system to work is just one more hurdle for them. We might be successful in teaching them these tricks during the initial implementation of the software. However, as the worker leaves a job and trains a replacement, these tricks becomes fuzzy and explanations are sometimes lost. When the worker in the facility begins to make errors in reporting, and/or errors in interpreting data, the information becomes less reliable, and therefore, less useful as a management tool.

**Costs**

With a production model (see Figure 3, shown earlier) the cost of the process is totaled by adding the costs of A and B. This total is allocated to X and Y based upon the rules of the model. These rules are user defined and may be a
straightforward split of costs based upon the volume of output. There may be an attempt at margin equalization to distribute the costs through percentage calculations forcing the product with higher market value to carry more of the production costs. There is no right way to apply costs. It is a business decision. It is important to note, however, that costs can be calculated and tracked for both X and Y and that users have the flexibility to define how costs are applied to each.

In the BOM method (Figure 4), the costs of X can only be calculated by adding the costs of A and B and subtracting the value received from the sale of Y. This is a limitation in the logic of BOMs that assume that everything other than the end item is consumed and therefore all costs below the produced item are totaled. This logic forces the user to assign the cost of Y. This would support a Net Realizable Value method of costing Y and X, and the “market value” of Y would be a credit towards the cost of producing X. There is no ability for the system to distribute total costs between X and Y. In the context of actual production, if there were yield variations (or the proportions of X to Y changed for some reason), there would be no assistance from the system in determining the actual costs of Y. (The actual cost of X is also in question.)

If Y were a by-product that had costs associated with its disposal, the assigned cost of Y would have to be entered as a negative. Using the same logic as the quantity required (a negative times a negative equal a positive), the cost of Y would then be an additional cost to the total cost of the production of X. While this logic works mathematically, this is a confusing and complicated concept to explain to workers. If the costs of disposal were different than expected, then these costs would not be reflected in the actual cost of producing X unless the cost of Y were manually adjusted.

And these are just the simple examples. What if Y is a by-product but is produced at process Stage 1 while X is produced after process Stage 3? Clearly the cost of producing Y is less than the cost of producing X, yet in a negative consumption concept there is no ability to model this. Fundamentally this is because the BOM model is completely divorced from the operations (process stages) model. To understand actual costs of multiple produced items in a complex process the negative consumption concept must be replaced with a more logical model representing the inputs and outputs of the actual processes stage by stage.

More Than One By-Product
You begin to see the limitations in a convergent system when trying to answer the following questions modeling both W and Y as negative consumption.
Figure 7. Actual Structure

What is the cost of Y? When will Y be available for further processing? Is C part of the cost of Y? Is C part of the cost of W? What is the cost of W?

The simple answer is that a BOM can not support either without serious tricks being played. A process model designed for multiple inputs and outputs, stage by stage, with full support for recycles, is the only answer for the complex chemical producer.

Planning and Scheduling

In Figure 4, Y is modeled as a negative consumed quantity. How is a negative quantity reflected in a time-phased, projected material or available to promise (ATP) inventory? In actual fact, Y will be produced and available after the consumption of A and B because it is the duration of the manufacturing process that determines when Y will be produced. However, in the negative consumption concept, Y’s availability is unclear since the timing is not visible in the BOM. The logic of the bill must be amended if you do not want to see Y as available on the same date/time as the required date of A and B.

A more complex problem for planning is when Y has independent demand in the marketplace. How do you model the master production demand for Y if it is a consumed item? In a BOM architecture, one can not model this. In a process model that anticipates multiple outputs, master scheduling of any output is supported. This is especially important if both outputs have independent demand. Additional support is required to ensure that the user can dictate which output is planned first (thus controlling which output will be produced in excess if the demand is not balanced).

Consumption Reporting/Lot Tracing

Because Y doesn’t appear as a “produced” material in the BOM model, the expected production of Y is unclear in the rest of the system. Furthermore, how does the operator report the actual production of Y? Often an operator will use a miscellaneous receipt, with the result that the connection to the production
order is lost (and lot tracing seriously compromised). If Y is a product that is sold in the marketplace, how is lot tracking back to the process that produced it possible? Remember that the logic of the BOM system says that everything except X is consumed, and therefore, even if Y is reported using a negative issue transaction, Y will appear on lot tracking reports as a consumption of a negative quantity. This must be correctly interpreted by all end users accessing this information.

**Theoretical Calculation of Co-Product Quantities**

A characteristic of the chemical industry is that the actual consumption is not reported until well after the fact. A valve at the tank is opened and the reactor is filled and products are produced. At the end of the period (shift, day, week), a cycle count determines the actual quantity left in the tank and, therefore, what has been consumed during the period. The inventory usage reporting then is done to the system.

However, users need the best information about available inventory as soon as possible. The reporting of “actual aggregate” usage based upon tank measurements should be used to adjust the transactions which have been driven by the system. As each quantity produced is reported, the ERP system should be calculating a theoretical quantity consumed of ingredients. This is known as theoretical consumption or backflushing. This feature exists in some bill of materials systems but is typically linear: consume 20 tires for 10 bicycles produced, 400 tires for 200 bicycles produced. This logic falls short in the following situations:

- If any of the consumed quantities depend on Y, how do the quantities of A and/or B get calculated?
- If a catalyst is a batch quantity, and not linear, what will be calculated if we have yield fluctuations?
- What happens if consumption of one ingredient is directly proportional to another consumed ingredient and not the outputs from the process?

**Accessing Master Files**

The key to all information in a BOM-based system is the produced item. With the model number of the bicycle, you will find out all of the components required to produce that special version. How do you access the feedstocks required when you are refining oil? What do you call that “Bill of Material”? The product produced from the last stage? Who will remember it?

A process modeling system that plans for multiple outputs provides for the naming of each model. “Processing X through Line 8” might be a name of a model in the Chemical ERP system. This is logical to all end users (it is probably how they speak about production) and supports the idea that X can also be made on lines 6 and 7.

**Recycles**

A typical problem of the chemical industry is the appearance of recycling
streams (including recycles, regenerate or catalysts) in the manufacturing process. These recycles create another problem. In Figure 8 we can see an example of how Y is used as a carrier material and is regained at the end of the process. Figure 9 shows the modeled structure in the BOM. Y (here +Y) is consumed and is regained (-Y). Now we begin to see the failure of the BOM-based systems because they do not show the time phasing through the process. The recovery of Y logically happens at a later stage than the input of Y, but the bill can not model this.

Also, mathematically we have a problem. The net requirement for Y is calculated as \( Y = (-Y) + (+Y) \). Clearly the net requirement is not the physical requirement, since in order to start the process we need the full quantity of Y (the \(-Y\) in this instance). How do we communicate this to the warehouse personnel? How is this presented on the pick list?

![Figure 8. Actual Structure with Recycles](image1.png)

![Figure 9. Structure in a BOM](image2.png)

How does the MRP planning logic handle such a situation? How are the costs of Y determined? The designers of BOM-based systems have figured out how to avoid all of these issues: the inclusion of both a \(-Y\) and a \(+Y\) is prohibited.