White Paper

Improving Plant Performance and Flexibility in Process Manufacturing

With an Example from the Food and Beverage Industry

Changing the rules of business™

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I. Introduction

In the production environment, it is well known that process manufacturing is different from discrete manufacturing. Finished goods are created through a continuous manufacturing process that involves the creation of multiple intermediate products that are then converted into tens or even hundreds of finished goods. Production recipes are very different from bills of material. Lead times are often less flexible. Cleaning procedures are mandatory, more frequent and often more disruptive than equipment maintenance in discrete manufacturing. Filling and packaging lines are generally more automated. Batch control and traceability are enforced throughout the entire production process. The list goes on.

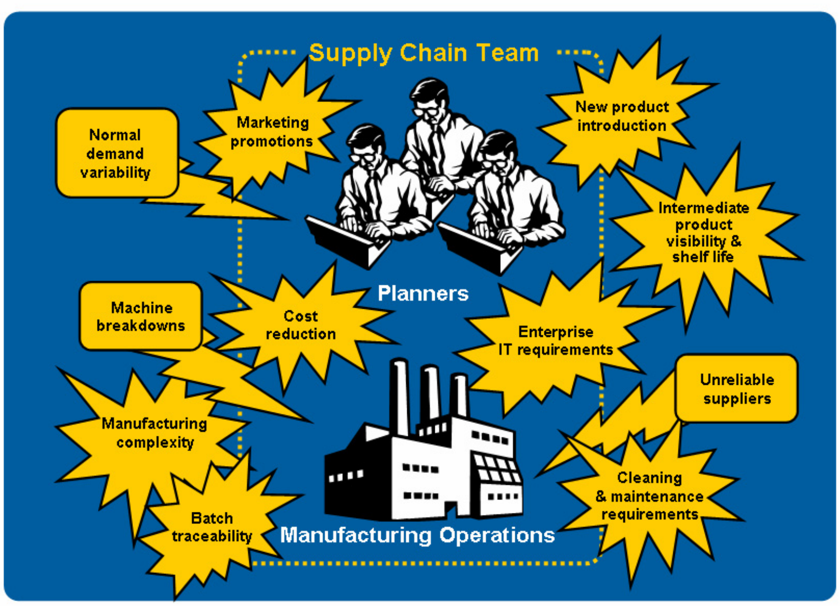
One result of all of these differences is that while there are many more database transactions associated with discrete manufacturing, production planning and detailed scheduling are generally more difficult in process manufacturing plants than in work-center-based manufacturing or line-based assembly processes. In fact, only project manufacturing (e.g., aerospace and capital equipment) and automobile manufacturing involve comparable levels of scheduling complexity.

This white paper reviews the planning and scheduling challenges facing many process manufacturing companies, and provides information about new approaches that are making it easier to manage process manufacturing operations to achieve new levels of performance, control and flexibility.

II. Business Challenges in Process Manufacturing

Today, manufacturing companies generally produce a greater variety of products in smaller runs than they did in the past because of the twin imperatives of competitive marketing and overall supply chain economics. This is especially true for consumer-driven manufacturers who must continuously differentiate themselves with a steady stream of promotions and new products – while continuing to offer consumer favorites. Meanwhile, supply chain economics dictate the need to continuously reduce total distribution network inventories while increasing flexibility to better support marketing promotions, special orders and order adjustments in a demand-driven world.

Forces Attacking Supply Chain Teams



All manufacturing companies strive to achieve high service levels with good cost control and operating efficiency. Most work hard to maximize the return on their substantial investments in enterprise resource planning (ERP) and supply chain management (SCM) transaction systems. But in process manufacturing in general, and in the consumer packaged goods (CPG), food and beverage (F&B) and pharmaceutical industries in particular, certain business challenges stand out:

A. Coping with a High Level of Demand Variability

There are numerous sources of demand variability in high-volume consumer product businesses:

- Promotional programs that impact customer demand in ways that are extremely difficult to foresee
- Consumers that sometimes substitute one product for another, and sometimes don't
- Seasonality
- Competitor behavior: new product introductions, promotions, distribution partnerships, etc.
- Distribution network breakdowns

The bottom line is that, in many cases, demand forecasting has real limitations. It is fine for general, long-range production planning, but there is just too much inaccuracy and uncertainty for production scheduling. For the management of manufacturing operations, what is needed is a multi-pronged strategy that provides:

- Careful promotion impact analysis and forecasting
- Steady adjustment of distribution node safety stocks (store level and warehouse) based on demand pattern analysis
- Flexible, daily production scheduling that is able to fine-tune the production plan and deliver it based on the latest information from all fronts

Strategies to Manage Demand Variability	
Requirement	**Solution**
Promotion analysis and forecasting	S&OP, collaborative demand planning
Adjustment of safety stocks	Inventory optimization
Flexible and agile production	Integrated planning and scheduling

B. Coping with a High Level of Complexity in the Manufacturing Process

Scheduling in process manufacturing requires coping with the special challenges associated with:

- ***Integrated scheduling of intermediate products and finished goods.*** The efficient production of intermediate products involves a set of costs, activities, constraints and process preferences. The production requirements of intermediate products cannot be simply computed by back-propagation of finished goods quantities. Intermediate products are produced in batches and can be stored for a very limited time. The production of intermediate and finished products must be tightly synchronized. Only by looking at them together can the entire schedule be optimized. And in looking at them together, a business must take into account tank capacities, conversion process times, flow rates and a host of other operational considerations.

- ***Respecting cleaning rules while minimizing total cleaning times.*** Cleaning rules on tanks, fillers and packers can be extremely complex. For example, equipment may need to be cleaned based on frequency (no less than every X hours),or the number of batches produced (every Y batches), or when switching from one type of product (e.g., a product containing an allergen) to a different type of product. And the rules can overlap: A storage tank, for example, may need to be cleaned every three batches but also when switching from chocolate to vanilla. Cleaning a tank can often take five or six hours. Most cleaning activities require dedicated personnel and equipment that may or may not be available at the ideal time when ideal for the production schedule. In short, the scheduling of cleaning activities is a lot more complex than simple production changeovers. In some manufacturing environments, the minimization of total cleaning time (while respecting all cleaning rules) is one of the main sources of productivity improvement.

- ***Minimizing the number of changeovers.*** Whenever recipes are switched or packaging is changed, some waste will be generated. For example, when a yogurt plant switches from strawberry to peach yogurt, it is unavoidable that some unwanted "strawberry-peach" yogurt is produced. Similarly, switching from 12-ounce cups to 32-ounce cups may result in some waste during the changeover process. Minimizing the number of changeovers to the fewest and least wasteful is very helpful. Optimizing this in conjunction with efficient scheduling of cleaning activities can be a very big win for productivity.

- ***Managing finished product and intermediate product shelf life.*** In all fresh food and many other process manufacturing industries, intermediate and finished product shelf life adds to the complexity of the manufacturing process. Typically, an intermediate product cannot be stored in a tank forever. Once it completes its maturation process, it must be used or thrown away. Similarly, once a product is finished, it has a limited time in which it can be used before it expires and has to be thrown away. The clock is almost always a factor.

C. Regulatory Compliance and Traceability

Health and environmental regulations play a significant role in process manufacturing, especially in CPG, pharmaceuticals and chemicals. These regulations impact both the production and distribution systems. Batch control and traceability are fundamental. Cleaning requirements are significant and must be executed precisely based on complex rules that may require awareness of factors that include throughput, elapsed time and process readings. Companies must be able to respond quickly to a process control failure and remove all contaminated products from the production environment. Traceability must be enforced from receipt of raw materials to intermediate product production to finished goods production on to the filling and packaging lines, distribution pallets and shipment orders.

D. Improving Profitability

Process manufacturers tend to operate under intense competition. While not all process manufacturing products are "commodities," product differentiation is not the same as it is for manufacturers of $5 million machines or $500 million airplanes. Margins are much tighter. Many of the top companies in the world with the greatest strengths in terms of economies of scale, market share and brand/price premium consider themselves fortunate to make 8%-9% in net income. Given the constant pressure on prices, margins can often be maintained only through a relentless search for productivity improvements. Improvements in efficiency – asset utilization, waste minimization and inventory reductions – are generally required for any significant improvement in profitability.

E. Balancing Multiple, Often Conflicting, Goals

Functional goals can often be in conflict, and must be reconciled or at least balanced when developing an optimal schedule. Some of the primary organizational tensions:

- **Sales and Marketing vs. Manufacturing Operations**. From a sales and marketing point of view, the best production plan produces as many stock keeping units (SKUs) as possible and does so in small runs every single day. This is driven by marketing's need to provide the best possible customer service while coping with demand variability. In consumer-driven industries, it is also often important to refresh the brand with a steady stream of new products and new product extensions. In contrast, manufacturing operations wants longer runs and predictable, compact schedules with fewer shifts, operating lines and changeovers, and minimized waste.

- **Quality Control vs. Manufacturing Operations.** In process manufacturing, production batches often have to be carefully controlled for quality. In yogurt production, the quality control aspect is about consistency of taste, sanitation, allergen control and truth in labeling. Ideally, production batches should never be mixed in a tank, and machines should be cleaned as often as possible. In contrast, for manufacturing, the main challenge is to manage all manufacturing constraints and still be able to keep unit costs low – maximizing resource utilization and generating high throughput and return on assets (ROA), while minimizing changeovers and waste.

The best production schedule has to balance multiple goals. The following table captures some of the different objectives and metrics, showing how they push the ideal schedule in different directions:

	Marketing	Manufacturing Operations	Quality Control
Keys to Success	• High or perfect order fulfillment • Agile and effective response to changes in demand • Steady addition of new products • Product freshness and shelf life	• Longer runs with fewer changeovers & cleaning activities • Finished goods inventory buffers • Fewer products • Reduced waste	• Tight process control on intermediate and finished goods products • Product freshness & shelf life • Aggressive cleaning rules
Key Metrics	• "Moment of truth" product availability • Market share • Success of promotional campaigns • Inventory corridor performance	• Unit costs • Schedule compactness • Schedule predictability and balance • Operational efficiency	• Product consistency • Regulatory compliance

In short, the optimization of a production schedule should take into account all of the different goals, costs and operating constraints simultaneously. Sophisticated optimization models that support real trade-off analysis, providing good explanations and scenario comparison, are a key to this process.

F. Leveraging IT Investments for Lower Total Cost of Ownership

Most process manufacturing companies use one ERP application as their transaction backbone and "system of record." Specialized, best-of-breed applications are still sometimes necessary –

especially in the area of analytics – but an important goal remains to maximize the return on investment (ROI) obtained from the multimillion dollar investment made in an ERP/SCM transaction management system. Where possible, best-of-breed applications should supplement, not compete or overlap with, existing ERP and SCM functionality. The integration of any such complementary applications should preserve an enterprise's investment in a "single version of the truth." There should only be one repository of master data and transactional data.

III. Food and Beverage – The Example of Yogurt Production

In the F&B industry, many products such as ice cream and other dairy desserts, baby food and beer are quite similar to yogurt in terms of manufacturing process steps, while others such as cookies, biscuits, candy, pet food, pasta, soda and juice are quite different. Some of these are simpler, while some are equally complex – but complex in different ways. Dry pet food, for example, has a lot of complexity on the filling line, where it is sometimes necessary to mix different shapes and flavors of kibble in one finished goods pack. But at the same time, these various industry segments share many operational challenges as well as the business pressures associated with the need to improve margins, market share and customer service. Continuing our pet-food comparison, here is a list of operational production concerns that are common to yogurt and pet-food production:

- Multiple intermediate products feeding many finished goods (tens feeding hundreds) with limited storage capacity for intermediate products
- Production bottlenecks and options
    - In dry pet-food production, one oven feeds one extruder, but extruders can feed one or many packing lines
    - In yogurt production, one fermentation tank feeds one storage tank, but storage tanks can feed one or many filling lines
- Stringent batch control and traceability requirements
- Complex set-up, changeover and cleaning rules
- High consumer-driven demand variability

The following discussion of the scheduling challenges faced in the yogurt production process provides a good example of the issues facing the F&B industry in general. After this review of the specific challenges in the yogurt production process, the whitepaper will look at some of the particular needs and requirements found in the pharmaceutical industry, followed by a profile of how state-of-the-art optimization technology and solutions can improve operational efficiency and business performance.

A. Yogurt Production Process Steps

Making yogurt generally takes three to four days and involve nine distinct steps:

1. **Preparation** – mixing the ingredients for an intermediate product: cow milk, low-fat cow milk, soy milk, cream, sugar, powdered milk, etc.
2. **Pasteurization** – ensuring a bacteria-free starting point
3. **Fermentation** – creating various bacteria with specific health benefits
4. **Cooling** – turning white mass into an intermediate product ready for use
5. **Storage** – placing the white mass in tanks connected to the finished goods production lines
6. **Finished goods production** – filling containers of various sizes, often with supplemental ingredients such as fruit, granola or flavorings
7. **Packaging and labeling** – sealing the containers and boxing them for shipment
8. **Product maturation** – allowing the product to mature
9. **Final quality check** – ensuring the safety and quality of the product

The following diagram illustrates the first seven steps. Preparation tanks are connected to one or more pasteurizers, which are connected to fermentation tanks, coolers and storage tanks. Both the preparation tanks and the fermentation tanks work in controlled batches, while the pasteurizers and the coolers are continuous process steps.

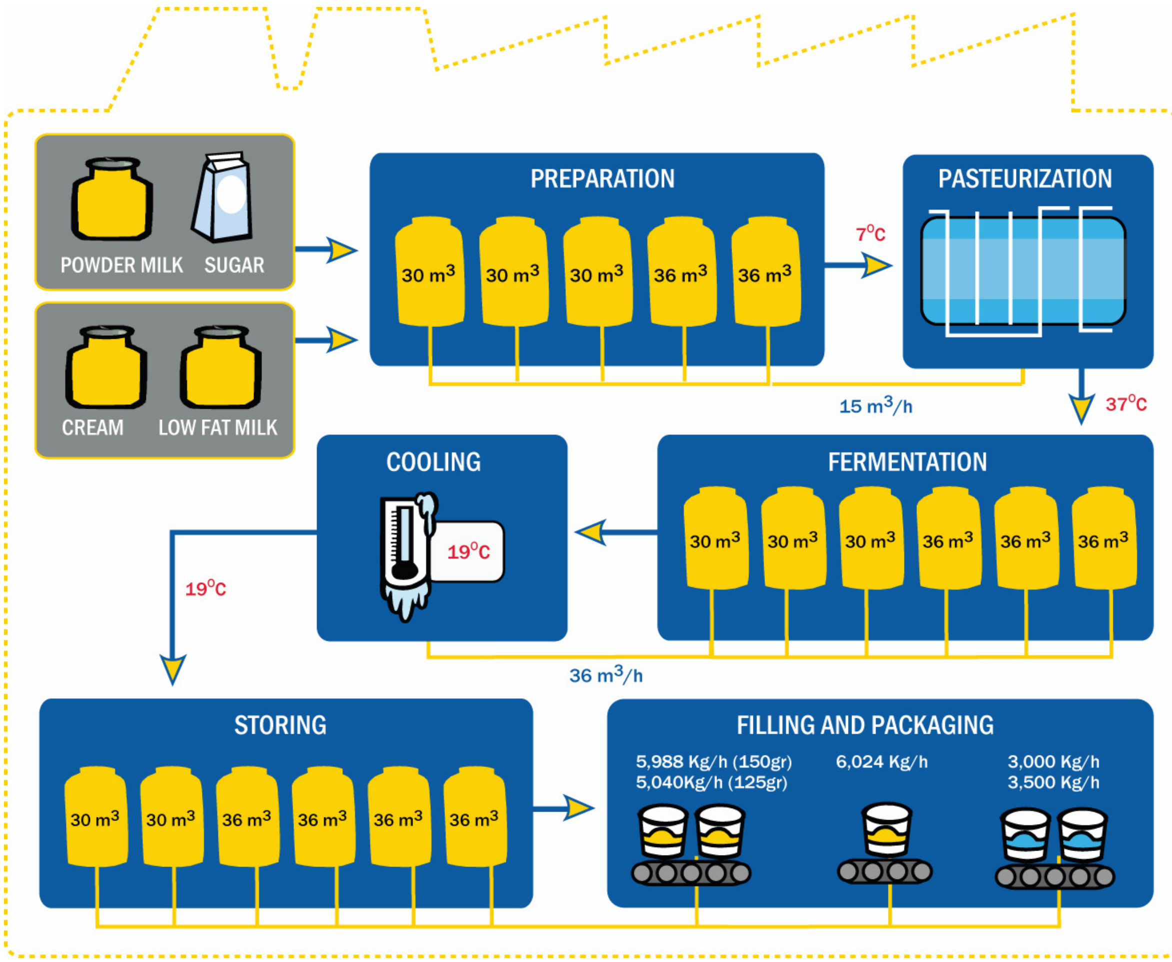
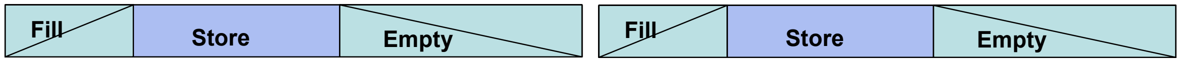


Diagram of yogurt production process at dairy plant

The scheduling challenges associated with the first five steps are significant in themselves. For example, both the preparation tanks and the fermentation tanks must be emptied completely at the end of their process steps. Adding to the difficulty, there is a maximum amount of time the white mass can be stored in the storage tanks, and the 10 intermediate products produced in the first five steps have to be perfectly fed into the production of 100-150 finished goods in the last four steps. Integrating the production schedules of intermediate goods with those of finished goods is, therefore, the biggest challenge of all in terms of the overall efficiency of the manufacturing process.

B. Tank- and Batch-Related Complexities

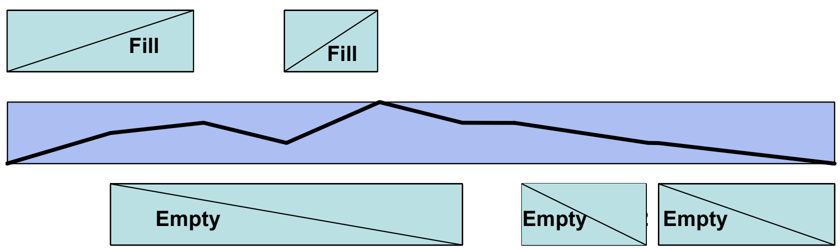
The scheduling of the tank-related manufacturing process steps can be very complex. While batches must be created that make sense for the finished goods production plan, there are scheduling constraints that must be respected that are quite independent of the finished goods plan. For example, the fermentation process can only start when the tank is completely filled, and only after fermentation is complete (typically in 12 hours) can the tank be emptied. Two batches can never be mixed together; a filling activity can only start after the last batch has been completely emptied, as shown in the following illustration. And, of course, a cleaning step may be scheduled between the emptying of one batch and the filling for the next batch.



However, in the case of the storage tanks that directly feed the filling lines, additional rules can come into play. For example:

- Tank reservoirs may be allowed to begin being consumed before the completion of their filling process
- Tanks may receive fillings before they are completely empty
- Batches may be mixed in a storage tank

The next diagram illustrates a scheduling view of what happens when batches can be mixed (a storage tank is replenished before it is completely emptied) and the filling machines are allowed to start drawing from the tank before the end of the filling process. The top and bottom rows show different activities (filling and emptying) on one tank, while the middle row shows the inventory of material in the tank as it goes up and down.



It goes without saying that this tremendous degree of flexibility can be useful in high-volume production. Sometimes, the coordination of intermediate product production with finished goods production requires this type of aggressive tank utilization. To keep 10-15 filling and packaging lines efficiently producing 100 finished goods based on 7-10 intermediate products produced using a set of 100 tanks certainly requires the sort of tank capacity management and visibility shown in the diagram.

From an optimization point of view, tank management makes the scheduling more challenging. First, the intermediate product in each tank must be kept between the minimum and maximum tank capacities. Second, the scheduling algorithms need to track reservoir levels, consumption rates and replenishment rates over time. It is too complex a job for spreadsheets and scheduling applications designed to manage job-shop production with a bill of materials and Kanban-based replenishment system.

C. Cleaning and Changeover Activities

In yogurt manufacturing, cleaning is very important because flavors and colors are frequently changed, and health regulations for bacteria control, nutrition and ingredient labeling must be met. There are a significant number of guidelines for cleaning the various tanks, lines and filling machines. Taken together, cleaning activities are a significant cost and source of disruption in terms of smooth, balanced production. Some cleanings take two to three hours, others five or six hours. The more efficiently cleaning activities can be timed, the more yogurt a plant can produce.

A few examples of the cleaning rules in a yogurt plant:

- A thorough cleaning of the filling machine is required if an allergen is present in one product but not in the next one being produced

- A filling machine must be cleaned at least every 36 hours
- Storage and fermentation tanks must be cleaned after every X batches or Y hours
- A preparation tank must be cleaned immediately upon emptying
- A filling line must be cleaned if idle for more than eight hours

The different types of cleaning activities require special cleaning machines. These machines are expensive and purpose-made, and must be carefully scheduled as they are typically in short supply relative to demand. In the language of an optimization model, the cleanings should be minimized while respecting health regulation constraints and cleaning machine availability and maintenance. Again, this is not a job for spreadsheets.

D. Other Operational Constraints

Beyond the cleaning and changeover activities that must be scheduled, there is another cluster of operational constraints that must be considered. Tanks and filling lines are linked by physical connections. For example, storage tanks 1 and 2 may be connected only to the first filling line, and storage tank 7 may feed filling lines 10, 11 and 12. In most plants, these connections are fixed, although, in some cases, they can also be moved. Also, machine-product compatibilities are fundamental constraints in process manufacturing. Because the size or shape of the containers or the filling capabilities of the equipment vary, not all products can be produced by all machines.

Last, but not least, preferred production sequences do exist and should be respected as much as possible. Much of this has to do with taking advantage of product similarities. A strawberry yogurt without granola is very close to one with granola from a production efficiency point of view. Similarly, making 32-ounce containers of vanilla yogurt after making 8-ounce containers may be more efficient than switching flavors. It depends on the trade-off between switching container sizes and switching flavors. But this decision has to be made in the best interests of the schedule as a whole, which is what optimization is all about.

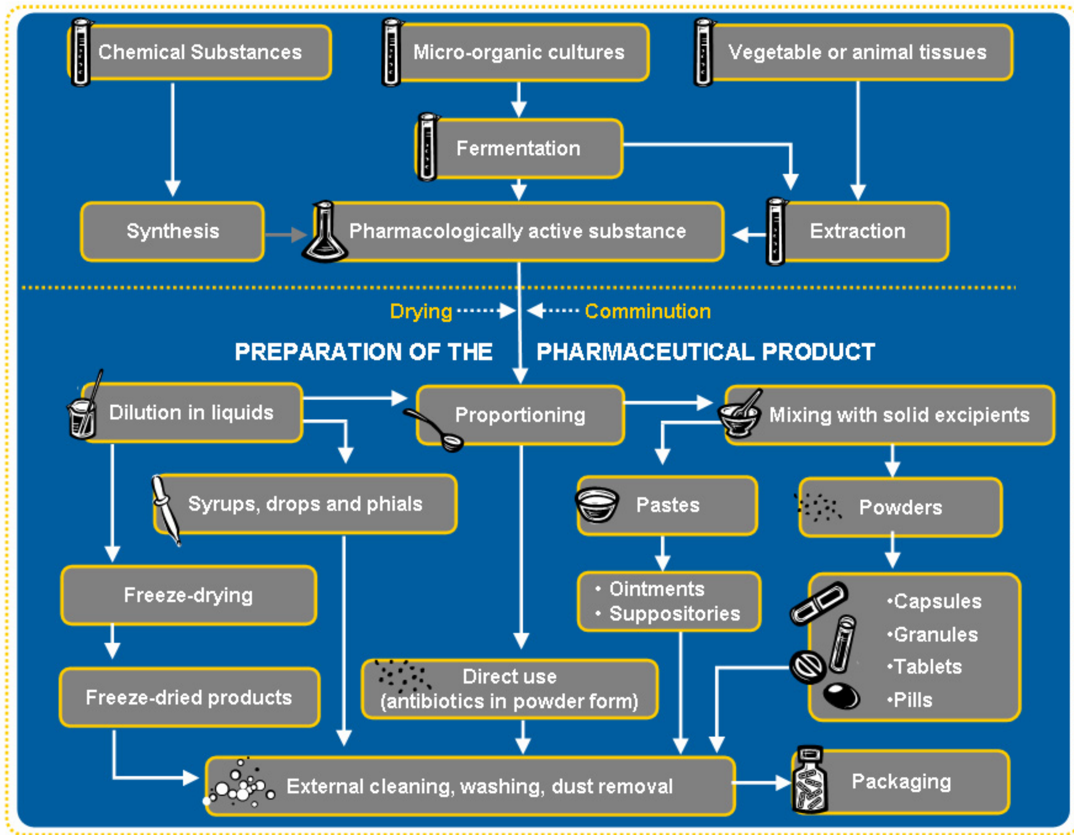
IV. Special Challenges in the Pharmaceutical Industry

The pharmaceutical industry shares many of the operational challenges just profiled for F&B. Both industries purchase raw materials and make intermediate products that are turned into finished goods. Both share the headaches associated with managing tanks, complex cleaning rules and traceability requirements. But the economics of each industry are very different., Beyond the well-known realities of very high research and development (R&D) costs and a major shift to biology-based innovation, the following points are significant when considering manufacturing efficiency in the pharmaceutical industry:

- ***Plants are bigger***. On average, they are twice the size of F&B plants. Most generate more than $500 million in annual sales, and the bigger biotech firms generate over $1 billion in annual sales.

- ***Often more intermediate and finished goods***. Some pharmaceutical plants are dedicated to high-volume products, but others produce a remarkable number of finished goods. Many average around 500 SKUs, and some produce over 1,000. And since intermediate products feed finished goods, the large pharmaceutical plants can produce more intermediate products as well.

- ***More process steps requiring more specialized equipment.*** This means longer cycle times and greater cycle-time variability with lower-than-average manufacturing capacity utilization. This is true in active ingredient manufacturing, drug formulation and packaging. The basic process flow can be seen in the following diagram:



Process flow for producing pharmaceutical products

- ***Poor forecast accuracy.*** While the demand patterns for most over-the-counter products are similar to those of the consumer products made by the F&B industry, prescription drugs are much harder to forecast. The distribution system is harder to understand, and in many ways, more fragmented. Cannibalization is a big factor, and the pickup of new drugs by physicians is difficult to predict. In general, order fulfillment service levels are lower than in F&B. Pharmaceutical companies are generally striving to reach 90% perfect order fulfillment, while F&B companies are typically in the mid-90s.

- ***Equipment is a much bigger part of the overall cost structure.*** Plant equipment is half the expense of opening a new pharmaceutical plant, and getting only 20 to 25 hours per week of actual production from many pieces of equipment is very expensive in terms of buying more equipment than optimal and downtime, increasing the number of bottlenecks and schedule breakdowns. In the United States, equipment expenditures almost doubled in six years, with capital equipment spending by pharmaceutical companies increasing from $3.1 billion in 1998 to $6.1 billion in 2004. And as of 2006, roughly 40% of the equipment held by pharmaceutical companies was more than 10 years old (Source: "*Annual Capital Expenditure*," U.S. Census Bureau).

- ***Low- and high-volume intermediate products.*** While F&B has low- and high-volume finished goods, it does not generally have the additional scheduling headache of having to handle low-volume intermediate product production. Pharmaceutical manufacturing has low- and high -volume production in both intermediate products and finished goods.

- ***Higher inventories.*** Both F&B and pharmaceutical manufacturing start with raw materials, but pharmaceutical companies carry much higher raw material inventories because so many more raw materials are used in the creation of the active ingredients and the production of the finished goods. As a result, the pharmaceutical industry has higher inventories for everything: raw materials, work in process (WIP), finished goods and packaging supplies. To put this into perspective, U.S. manufacturers of aseptic packaging sold $4.6 billion worth of supplies in 2004, and most of this went to the pharmaceutical industry (Source: Frost & Sullivan industry analyst). If better, more efficient and more controlled scheduling is possible, an almost certain benefit will be lower inventories.

- ***Process capacity and throughput are difficult to track.*** As the production process winds its way through the various process steps, the planner or scheduler is faced with a great deal of systemic complexity. One aspect of this is tracking how batches merge and split as they go through production steps. Another is at the level of the unit of measure. The unit of measure can be in liters in one step and cells the next, and then kilograms, thousands of tablets, etc.

- ***New manufacturing processes are introduced constantly.*** Most are driven by the introduction of new products, but some are driven by mergers and acquisitions and the increasing use of contract manufacturing for various production steps. In short, between the natural rate of innovation in the industry and the general trends toward consolidation and the rationalization of manufacturing, the average pharmaceutical plant changes goes through far more changes in a year than the average F&B plant.

- ***A challenging mix of batch and continuous production.*** While some processes are continuous or capable of taking advantage of continuous production efficiencies (e.g., roller compaction, tableting, extrusion, spray drying and packaging), other processes such as blending, granulation, drying and coating are historically, and in many cases, unavoidably batch. In the same way that coordinating finished goods production with intermediate product production is challenging, it is also inherently difficult to coordinate batch and continuous processes.

So, it comes as no surprise that in the *Pharmaceutical Manufacturing's Operational Excellence Survey, 2006,* the top three manufacturing goals considered important or very important were:

1. Reducing set-up times 96%
2. Increasing manufacturing agility 95%
3. Reducing cycle times 94%

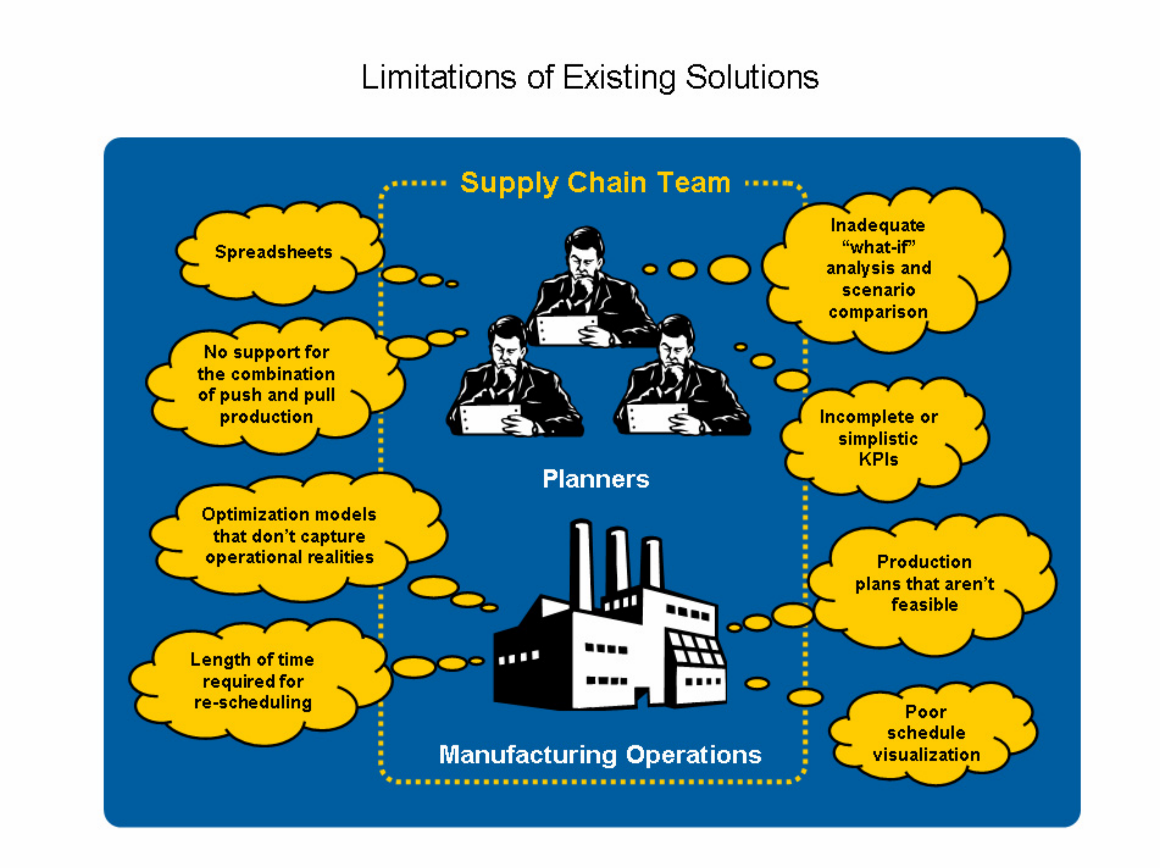
Making progress in the face of such complexity is a daunting challenge. There is no single, dominating solution or silver bullet for improving manufacturing efficiency. Pharmaceutical firms know this, and it is common to see process engineers and manufacturing operations personnel working on process and equipment design, maintenance schedules, and statistical analysis of process quality and throughput. But good planning and scheduling software can make a major contribution to achieving these key manufacturing goals.

The most important scheduling capabilities required:

- Optimizing the scheduling of production campaigns with their associated cleaning requirements
- Precise execution of multi-step recipes
- Management of fixed and mobile tanks with their connectors (this includes tracking material consumption and replenishment, as well as shelf life)
- Management of batches with merges and splits
- Tracking raw materials inventory, including consumption and replenishment with capacity awareness (this can be extended to include tracking the availability of water and electricity)
- Integrating the scheduling of active ingredient production with excipient production with finished goods production
- Planning and scheduling with different time horizons and granularity (in biotech, for example, a bioreactor may have a two-month schedule for generating a core raw material

that is then covered by a weekly or daily production schedule for intermediate products, finished goods and packaging)

V. Limitations of Current Production Planning and Scheduling Solutions



Historically, process manufacturing companies have been faced with a set of imperfect choices, forcing them to make compromises such as the ones below:

A. Disconnects Between Production Planning and Scheduling

What is planned for many plants today is, in fact, largely infeasible. Plans are developed without sufficient understanding of manufacturing operations. As a result, the plant can only take the production plan as a general target. It develops a production schedule independently. Negotiations and compromises between production planning and manufacturing operations can be difficult if they cannot share a detailed view of the realities of the production process. If the planners can't take operational realities into account when developing the production plans, optimal efficiency simply won't be achieved.

B. Scheduling Applications That Cannot Accurately Model Process Activities

Cleaning and batching rules, shelf-life limitations, resource connections, and the challenges associated with the filling and depletion of tank reservoirs are just some of the constraints that most scheduling solutions cannot model. In many process manufacturing production environments, these constraints are at the center of the manufacturing process. A scheduling solution that cannot model these constraints will generate incomplete and often infeasible production plans. And bad plans – whether technically feasible or infeasible – will result in suboptimal procurement of raw materials, more waste and lower throughput.

C. Use of Spreadsheets for Planning and Scheduling

Spreadsheets are easy to use, but their limitations make them risky in an enterprise environment. Spreadsheets cannot perform state-of-the-art optimization. There are no explanations possible regarding binding constraints. They cannot support all of the key performance indicators (KPIs) required. Their visualization capabilities are inadequate. It is easy to make a mistake without noticing it. There is no version control, and scenario comparison is difficult. Size limitations may come into play. In short, spreadsheets are simply not a professional or safe solution for the long haul.

D. Failing to Take Advantage of State-of-the-Art Optimization Techniques

Planning and scheduling problems are best solved using optimization – the most important mathematical discipline used in supply chain planning and execution and the second most commonly used form of mathematics in business as a whole (after probability/predictive analytics). However, only a few planning and scheduling solutions today utilize optimization technology to optimize both production planning and detailed scheduling. And most solutions that do attempt to perform global optimization use simple heuristics (rules of thumb) and dispatching rules. These methods tend to be single-dimensional and shortsighted, optimizing one dimension at a time.

For example, many systems can enforce a "minimize changeovers" constraint, but only a few can handle a more complex objective such as "minimize total changeover time and inventory while respecting cleaning rules and maximizing shelf life." In short, because they are sequential in their approach, they cannot and do not optimize the entire schedule. And as a result, they generate plans that require time-consuming manual adjustments, often driving planners back to their spreadsheet-based solutions.

E. Inflexible and Insufficiently Demand-Driven Solutions

Most detailed scheduling solutions focus on scheduling existing production orders and do not have the ability to take into account either manufacturing efficiency or last-minute changes in demand. What is needed is an ability to replan not only the sequence of activities, but the actual production orders themselves. Only this global optimization of both production planning and detailed scheduling can minimize inventories and work effectively with revised demand forecasts and last-minute orders and order changes

F. Solutions that Fail to Provide a Flexible Decision-Support Environment

Many planning and scheduling applications tend to be hard to use. One reason is that building a true decision-support application that works for both supply chain planners and manufacturing operations managers is difficult due to the following requirements:

- Excellent visualization – the ability to view a schedule with accompanying tabular data and drill-down capabilities
- Scenario comparison – the ability to compare operational assumptions, preferences, goals and scheduling details
- Sensitivity analysis – what would happen if demand were 5% greater for product A or if capacity were 10% greater on resource Y
- Interactivity – the ability to take a schedule as a starting point and make manual modifications based on human knowledge, and then get feedback from the optimization engine, helping prevent inadvertent mistakes
- Solution analysis – KPIs that capture the full set of financial, operational and hybrid financial-operational metrics for each planning scenario

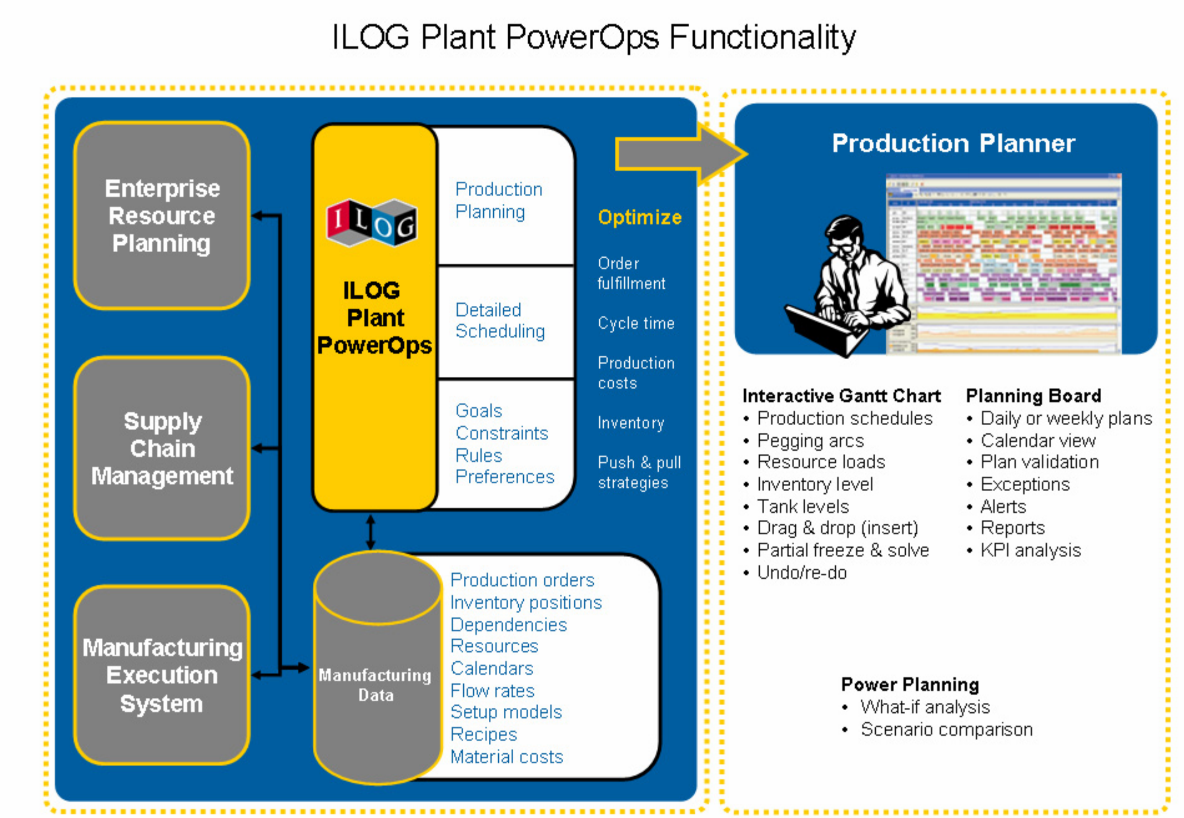
VI. ILOG Plant PowerOps – A Breakthrough for Planners

Based on state-of-the-art optimization technology developed by ILOG over 15 years, ILOG Plant PowerOps (PPO) is an application specifically designed to meet the planning and scheduling needs of process manufacturers. It generates production plans that maximize:

- Inventory corridor performance – by keeping finished goods inventories within inventory min/max targets
- Order fulfillment service levels
- Throughput – by minimizing changeovers and cleaning events, and maximizing resource utilization
- Profitability – from increased throughput, more compact schedules and reduced waste

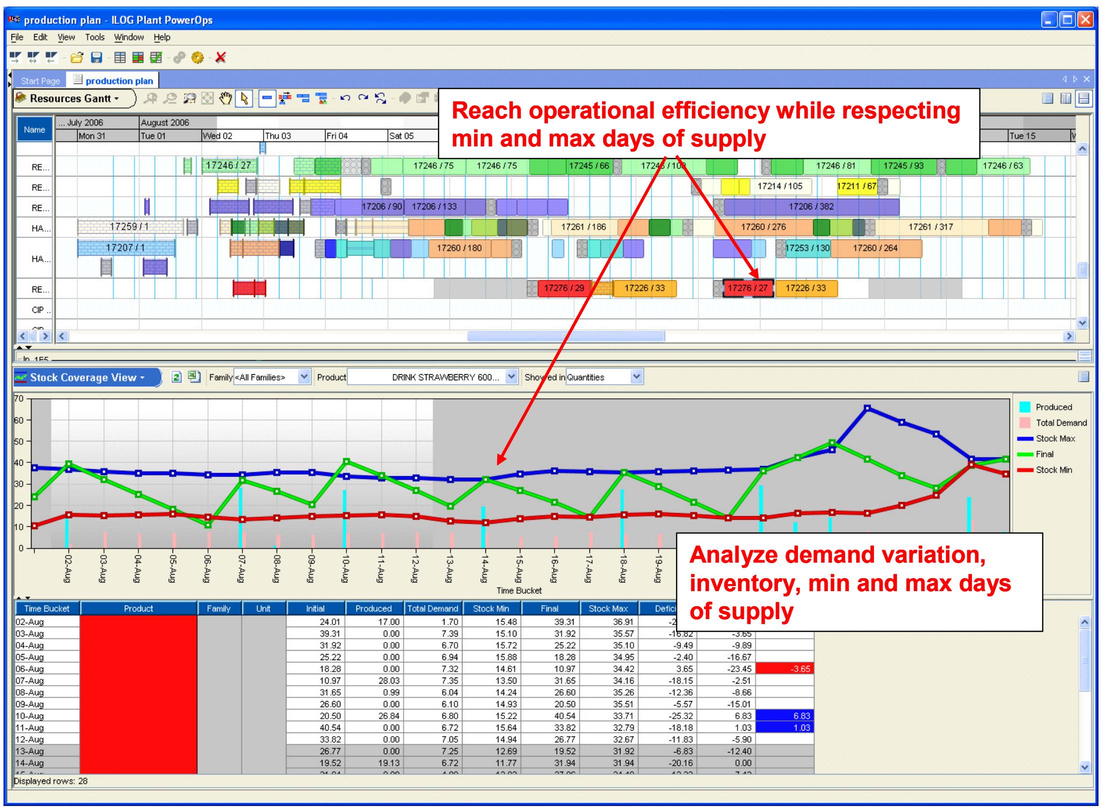
A. A True Decision-Support System for Planners

ILOG PPO offers powerful interactive capabilities to help planners improve plant performance. With sophisticated solution KPIs, what-if analysis and scenario comparison, complex trade-offs can be better understood. In addition, the ability to work with a recommended solution as a starting point is fundamental. Planners can freeze part of a solution and re-solve based on adjustments to scenario assumptions. They can also manually edit the recommended solution, receiving feedback on any violated constraints. The application's scope of functionality can be seen in the following figure:



The supply chain planner will typically define the minimum and maximum days of supply for each finished goods SKU with a penalty cost for violating these targets. Penalty costs can be higher or lower by product, and for violating minimums vs. violating maximums. The optimization models find the best possible schedule that minimizes the number of inventory-level violations while respecting all of the operational constraints, regulations and cost-minimization goals. Since the goals will always conflict to some degree, the planner must often negotiate with manufacturing operations to find the right trade-offs for achieving the best balance between level of service, product quality and operational efficiency.

Taken from ILOG PPO, the screenshot below has two panels and a table. The top panel displays a Gantt chart that shows the optimized schedule, with all activities assigned to specific resources and times. ILOG PPO has proposed an optimal schedule based on finished goods demand, intermediate product availability, cleaning requirements, and the target days of finished goods inventory for each product. However, the recommended schedule is optimized based on a deeper understanding of the total system than even this suggests. The final differentiation of state-of-the-art optimization lies in finding the best balance between push- and pull-based production strategies. What ILOG PPO does better than any other application designed to schedule multi-product process manufacturing is find the best balance between manufacturing efficiency-driven “push” strategies and demand-driven “pull” strategies. If making 10% more of one product and 20% more of another can eliminate one cleaning procedure and/or four hours of line idle time, it is probably worth it in a high-volume environment. In short, ILOG PPO adjusts the production orders intelligently without jeopardizing manufacturing’s ability to fill customer sales orders.



Analyze the impact of scheduling decisions

The bottom panel illustrates the “stock coverage view,” which shows the inventory corridor performance for one product – in this case, strawberry yogurt. The blue and red lines represent the maximum and minimum days of supply, and the green line shows actual inventory status.

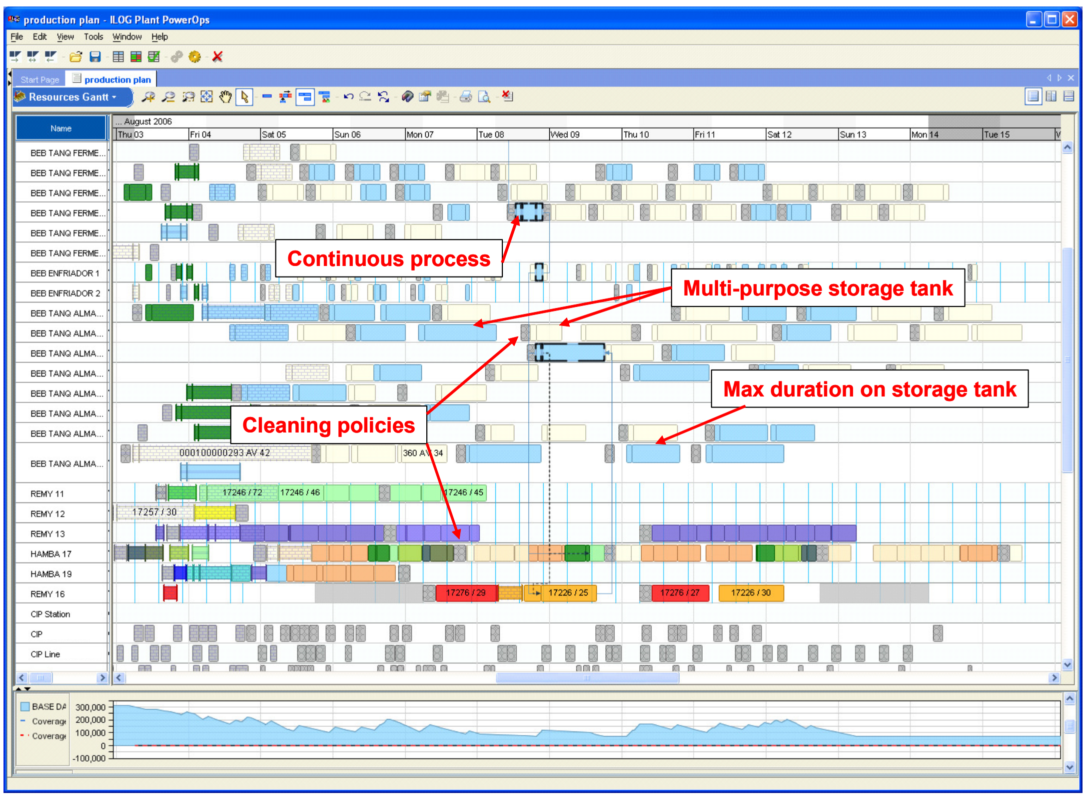
The table below the graph shows the status at the end of each day for quantity produced, demand filled and ending inventory, together with alerts regarding cases where the minimum or maximum days of supply have been violated.

The Gantt chart does more than show details of the production orders on the filling and packaging lines. It is also the main planning board for short-term scheduling decisions: Planners can add, remove, merge, split or move production orders. A sophisticated schedule repair mechanism with a solution checker helps planners perform these changes safely. If a delivery of strawberries is delayed, for example, the planner can easily change some near-term production orders from strawberry yogurt to peach yogurt, cancel some future peach yogurt orders, and add some new strawberry orders.

B. Coordinate Intermediate Product and Finished Goods Production

The next screenshot shows a more detailed view of the Gantt chart, including both filling and packaging lines and intermediate product production process resources (tanks and continuous flow equipment). In this example from yogurt production, three types of intermediate product, or “white mass,” are being produced, and are color-coded green, white and blue, respectively, in the ILOG PPO interface.

Different cleaning policies apply to the production of products made from these three intermediate products – both during intermediate product production and on the filling and packaging lines. Cleaning activities are represented as grey activities and require cleaning resources shared by both the intermediate product and finished goods production processes.



Manufacturing constraints that impact a schedule

As discussed previously, filling and packaging lines must be cleaned every three days, after a long idle time or when changing production from a product containing an allergen to a product without the allergen. Fermentation tanks, however, must be cleaned after every batch. Storage tanks are filled and emptied continuously, and once the white mass is stocked inside a tank, it is used within 24 hours. Sometimes it makes more sense to finish consuming an intermediate product in a tank to free up the tank for cleaning now rather than later. In the panel below, the Gantt chart shows the rising and falling inventory level of the blue-coded intermediate product as the tank’s reserve is replenished and consumed.

C. Proactive Identification of Potential Bottlenecks

ILOG PPO can also help planners proactively identify potential bottlenecks. A planner can simulate a marketing campaign's impact on production to make sure that manufacturing can actually produce enough to satisfy the expected increase in demand. Discovering hidden bottlenecks is extremely important. Imagine that the manufacturing bottleneck is on the packaging line today. Does the installation of a new packaging line guarantee increased production? Maybe or maybe not. If installing a new packaging line simply shifts the bottleneck to a different point (e.g., intermediate product capacity), the solution is not complete. Using ILOG PPO, planners can simulate different configurations of the plant and make long-term planning decisions as well as production planning and scheduling decisions.

D. Integrated Planning and Scheduling for Business Performance

Historically, production planning and scheduling have not only had practical difficulties working collaboratively across the "operational divide," but they have both been generally forced to make decisions about goal trade-offs without the benefit of the metrics that should really help them make the decisions in the best interest of the company as a whole. Everyone knows that poor plans lead to costly adjustments in manufacturing and suboptimal service levels, higher levels of waste, lost sales, etc. But what are the economics associated with current performance levels? What are the following improvements really worth to a manufacturing plant that makes $100 million, $300 million or $500 million per year in finished goods product?

- Reducing waste by 10%-50%
- Increasing throughput by 2%-5%
- Decreasing production costs by 1%-5%
- Improving standard order fulfillment by 2%-5%
- Improving promotional program order fulfillment by 10%-20%
- Moving from weekly to daily scheduling
- Moving from scheduling that takes days to scheduling that takes minutes
- Training new planners in days instead of in months

By optimizing and tracking different penalty costs, product unit revenues, equipment utilization, waste, inventory levels and other operational metrics, ILOG PPO can provide more sophisticated economic analysis than what has been possible previously. As a result, scenario comparison is no longer just about the visual pros and cons of two schedules; it is about the economic consequences of two schedules. Armed with this information and the ability to generate additional schedules based on revised assumptions, supply chain planners and manufacturing operations managers collaborate better than ever before. They have a truly balanced, shared frame of reference.

Integrated planning and scheduling and the ability to manage complex manufacturing constraints are key to improving business and plant performance. The supply chain performance improvement paradigms promoted by AMR Research (*Demand-Driven Supply Network*) and ARC Advisory Group (*P2B IOp – plant to business interoperability*) emphasize improving agility via the integration of planning and scheduling. ILOG PPO can help many process manufacturers improve their supply chain operations while integrating smoothly with SAP R/3, SAP APO PP/DS, Oracle and other ERP, SCM and MES applications.

VII. An Application Architecture for Planning and Scheduling

What is the best way to integrate a specialized planning and scheduling application into an existing IT transaction management environment? This is a crucial question that goes to the heart of any IT application architecture for manufacturing. There are two choices:

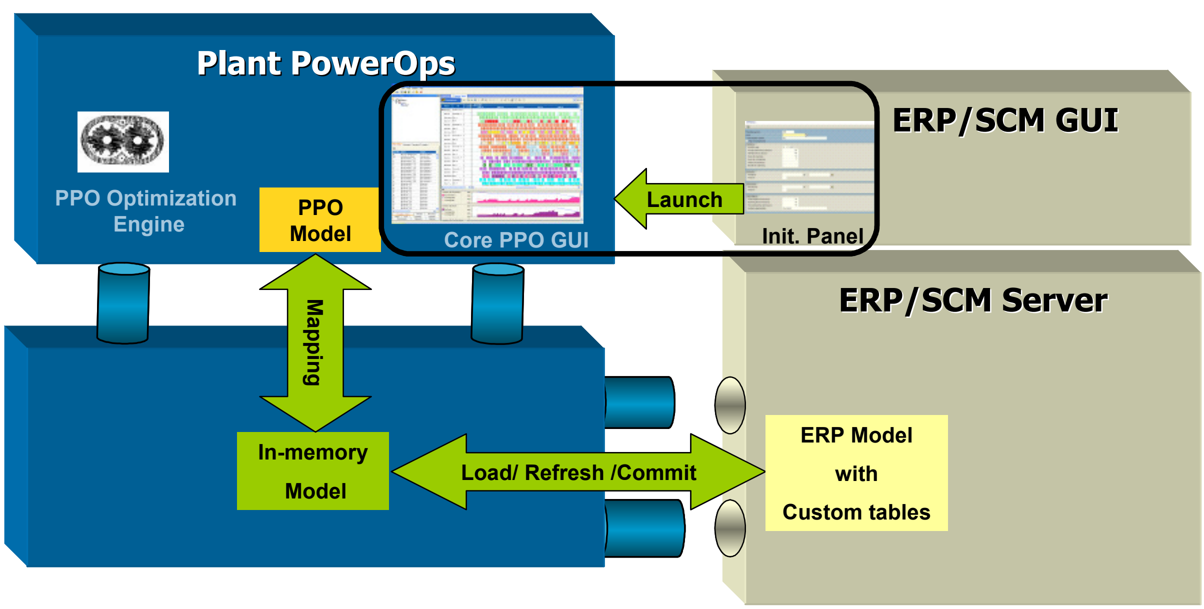
- The traditional approach has been to have a best-of-breed planning and scheduling application with its own database. This approach necessarily requires the synchronization of two databases, placing in question which system is the true "system of record" for manufacturing.

- The second, newer approach is an "analytic bolt-on" planning and scheduling application that utilizes the data residing in the ERP or SCM/APS "system of record" or the data in an intermediate database such as a data warehouse that is updated regularly by the ERP/SCM production system. In this scenario, the planning and scheduling "analytic application" gets its master data and transactional data from the ERP/SCM system of record when it executes an optimization process. As a result, there are no data synchronization issues. When the optimized schedule is finalized, the new and/or revised production orders are sent to the ERP/SCM system. Only then are they the "production orders of record."

In most cases, the analytic application is launched directly from the transaction application environment. This way planners do not have to go through a major transition when switching from production order management to production planning and scheduling. This integration approach dramatically simplifies life.

The architecture can fairly be described as one system with a planning and scheduling add-on instead of two independent systems. This approach offers all the advantages of sophisticated optimization in the planning and scheduling process, while maximizing the ROI obtained from having a unified transaction environment. For a company that is moving, or planning to move, its IT infrastructure toward a service-oriented architecture (SOA) paradigm, this approach is certainly the better option.

The following diagram shows the generic integration architecture of the ILOG PPO application – an example of the second integration approach. To provide all of the data that can be beneficially used by the planning and scheduling application, it may be necessary to take advantage of "flex fields," or custom tables in the ERP or SCM application's database. This is standard procedure with both SAP and Oracle, allowing a company to maintain all of its key master data and transaction data in the system of record.



ERP/SCM integration architecture

VIII. Keys to Success in Planning and Scheduling Projects

A few final considerations to help ensure success in any planning and scheduling project:

User acceptance cannot be taken for granted. An-easy-to-use interface is key for a complex decision-support system. Planners are "power users" whose frame of reference is spreadsheets. They expect to be able to quickly create scenarios, compare plans, generate reports, interact with the Gantt chart, etc.

Explanations are a key driver of success in using advanced optimization. Sometimes the recommendations of the optimization engine are difficult to understand or trust. Part of the gap is closed through application interactivity and decision-support features – what-if analysis, scenario comparison and sensitivity analysis – but part of the gap must be closed by messages that translate the mathematics of the binding constraints into plain, everyday language that everyone can understand.

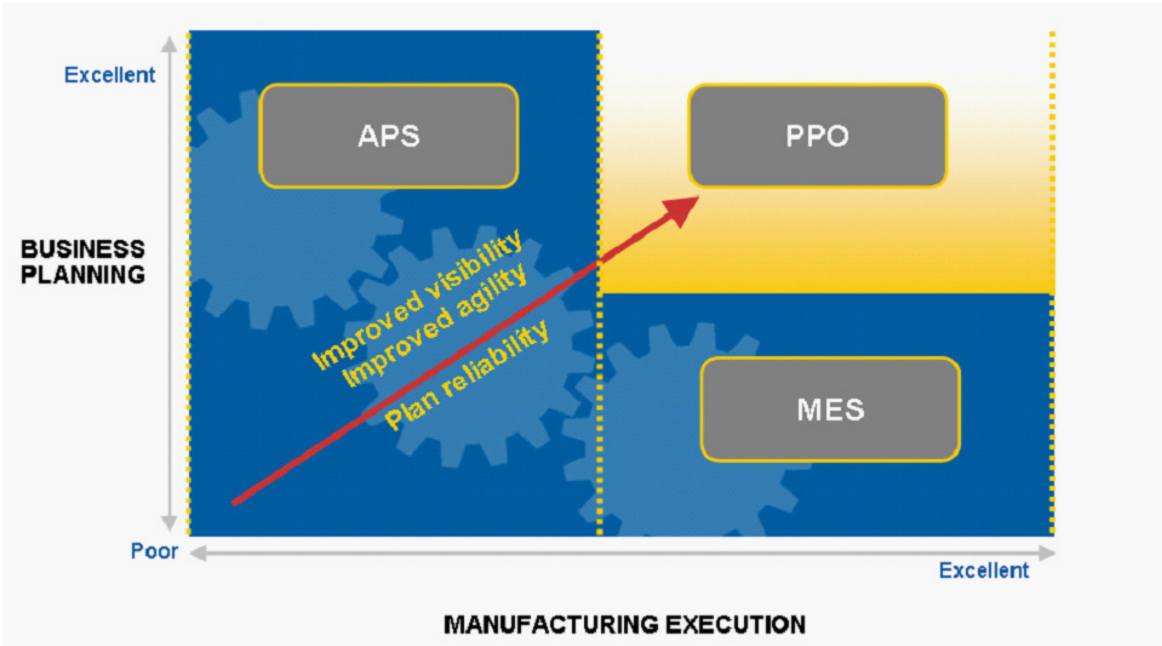
Understanding that an optimized plan or schedule is just an advanced starting point – not revealed truth or gospel. Planners and operations managers must be able to work with a recommended schedule and adjust it based on human knowledge. They should get recommendations, guidance, economic information, and feedback on attempted changes to a recommended schedule from the optimization engine, but they should not be handcuffed by it.

Software adaptability must match business requirements. A solution should be able to adapt to unforeseen changes in the business. This means assessing the ability of the graphical user interfaces (GUIs) and the optimization models to grow with the business.

Management of project risks. Planning and scheduling projects and optimization projects in general have extremely high ROI, but also real risks. The main ones:

1. *Supply chain planner and manufacturing operations participation*: Planning and scheduling projects are complex and involve several different roles in the enterprise. The right people must be involved from the beginning to the end of the project. Managers and project sponsors must make sure that enough time is freed from their day-to-day activities.
2. *Data readiness*: Input data, solution templates (plans and schedules) and KPIs must be defined early in the project. Only by working with solid inputs and outputs can optimization consultants fine-tune the planning and scheduling models.
3. *Over-modeling and scope creep*: The planning and scheduling models and the project requirements should be as simple as possible, while addressing the business needs. Any feature or modeling complexity must be justified by a clear business value. Over-modeling can be an extremely expensive mistake because it can cost time and money as well as slow optimization performance.

In conclusion, in today's manufacturing environments, there is often poor coordination between supply chain planning and the plant floor, leading to wasted resources and suboptimal order fulfillment and throughput. Insufficiently detailed operational models and inadequate optimization lead to poor schedules that, in turn, result in poor customer service and/or operational inefficiency.



With an integrated planning and scheduling approach that takes into account true plant-floor realities, a solution like ILOG PPO can improve the coordination between supply chain planning and manufacturing operations, resulting in a higher rate of on-time deliveries and greater process agility and schedule efficiency, while reducing unit manufacturing costs. ILOG PPO fills a real gap that exists today between the business planning and scheduling systems on the one hand and the manufacturing execution systems on the other.

IX. About ILOG

ILOG's leadership in the field of optimization is well established. Today, more than 1,000 universities use ILOG CPLEX in their research and teaching. And more than 1,000 commercial customers, including over 125 of the Global 500, use one or both of ILOG's two optimization technologies in their most important custom planning and scheduling applications. ILOG's complete system for building custom planning and scheduling applications is called the Optimization Decision Management System (ODMS).

ILOG is also a leader in supply chain applications. ILOG optimization engines are embedded in most of the top software applications in supply chain management, including applications from SAP, Oracle, INFOR, i2, Manhattan Associates, JDA, Emptoris, SmartOps, Areva, Siemens, Sabre, Boeing, PROS Revenue Management and others. In addition to providing optimization technology to software companies, ILOG is a leading provider of supply chain planning and scheduling applications serving the supply chain planning and scheduling markets. In addition to ILOG PPO profiled in this white paper, ILOG offers:

- ILOG Fab PowerOps (FPO) – An application for near real-time scheduling and rescheduling in front-end wafer processing in semiconductor manufacturing, supporting the primary manufacturing process steps of diffusion, photolithography and etch.
- ILOG Transport PowerOps (TPO) – An application for detailed planning and scheduling of for-hire and private fleet routes in multi-tier supply chains, providing better management of cost vs. service trade-offs, leading to an improved bottom line.
- LogicTools LogicNet Plus XE – An application for detailed supply chain network design, risk analysis and planning suitable for manufacturers, distributors and retailers.

- LogicTools Supply Chain Analyst – An application for multi-echelon inventory optimization with support for risk analysis and planning, as well as the establishment of safety stocks by product and location.

Along with general expertise in optimization technology, ILOG consultants have deep knowledge in supply chain network design, risk mitigation strategies, inventory optimization and detailed scheduling.

For more information, please visit www.ilog.com/products/scheduling for information on ILOG's detailed scheduling applications, including ILOG PPO, and www.logic-tools.com for information on the LogicTools division's supply chain planning applications for network design and inventory optimization.