Improving Plant Performance and Flexibility in Batch Process Manufacturing: With an Example from the Food and Beverage Industry

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Introduction

In the production environment, it is well known that batch process manufacturing is different from discrete manufacturing. Finished goods are created through a mix of continuous and batch manufacturing processes that makes multiple intermediate products that are then converted into hundreds of finished goods. Production recipes with both convergent and divergent material flows are very different from bills of material. Cleaning procedures are mandatory, more frequent and often more disruptive than equipment maintenance in discrete manufacturing. Filling and packaging lines are generally more automated, and batch control and traceability are enforced throughout the entire production process.

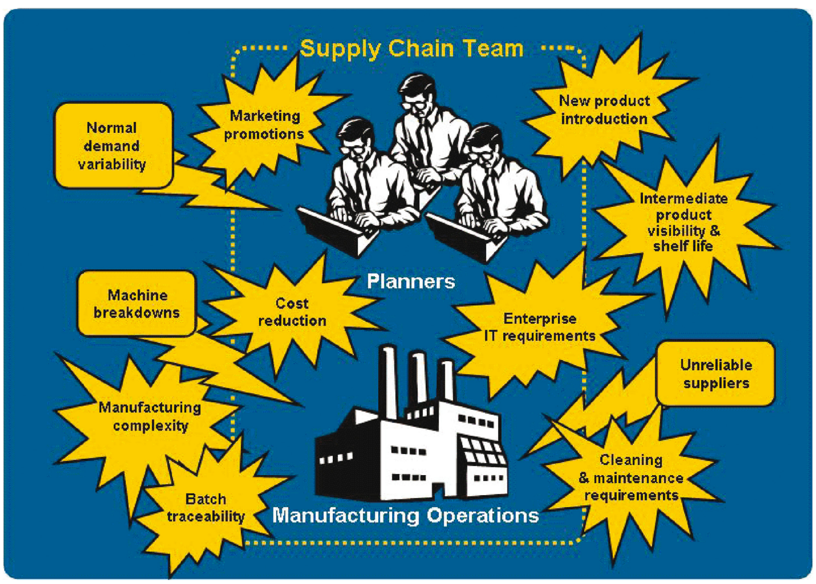
One result of all of these differences is that while there are many more stock keeping units (SKUs) in discrete manufacturing, production planning and detailed scheduling are generally more difficult in batch process manufacturing plants than in work-center-based manufacturing or line-based assembly processes.

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

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 goods 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 inventories while increasing flexibility to better support marketing promotions, special orders and order adjustments in a demand-driven world.

Figure 1: Forces Attacking Supply Chain Teams



All manufacturing companies strive to achieve high service levels with good cost control, asset utilization and operational 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:

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 who sometimes substitute one product for another, and sometimes don't
- Seasonality, which can make product demand fluctuate dramatically throughout the year
- Competitive behavior: new product introductions, promotions, distribution partnerships, and so on.

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, where you need to complement the forecasting system with flexible and agile production planning and scheduling.

For the management of manufacturing operations, what is needed is a multipronged strategy which provides:

- Careful impact analysis and forecasting for promotions
- Steady adjustment of distribution node safety stocks (store and warehouse levels) based on demand pattern analysis
- Flexible, daily production planning and scheduling that is able to fine-tune a 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

Coping with a High Level of Complexity in the Manufacturing Process

Scheduling in batch 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 of intermediate products cannot be simply generated by planning dependent demands for quantities of finished goods. Intermediate products are produced in batches and can be stored for a very limited amount of 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), the number of batches produced (every Y batches), or when switching from one type of product, for example, a product containing an allergen, to a different type of product. And the rules can overlap: A storage tank may need to be cleaned every three batches but also when switching from chocolate to vanilla. Cleaning a tank typically takes hours, and most cleaning activities require dedicated personnel and equipment that may or may not be available at an ideal time 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 still 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 is 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 cleaning activities can also 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. Customers require a remaining shelf life on the product delivered. This remaining shelf life may be different from one customer to another. Time is almost always a factor: manufacturers can throw away as much as one month of production a year because of incorrect management of shelf life issues.

Coping with 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 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 and on to the filling and packaging lines, distribution pallets and shipment orders. Regulatory compliance is typically managed by the manufacturing execution system, but it dramatically increases the complexity of planning and scheduling, and must be correctly modeled in order to obtain executable optimized plans.

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 to 9 percent in net income. Given the constant pressure on prices, margins can often be maintained only through a relentless search for productivity improvements. Generally, improvements in efficiency—asset utilization, waste minimization and inventory reductions—are generally required for any significant improvement in profitability.

Balancing Multiple, Often Conflicting, Goals

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

- **Sales and Marketing versus Manufacturing Operations:** From a sales and marketing point of view, the best production plan produces as many 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. By contrast, manufacturing operations want longer runs and predictable, compact schedules with fewer shifts, operating lines and changeovers, and minimized waste.

- **Quality Control versus 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. By 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.

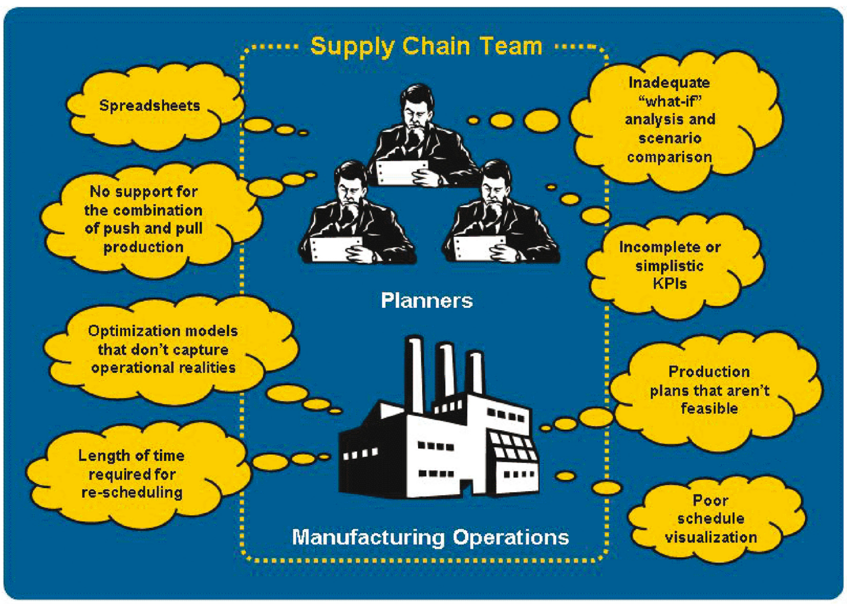
The best production schedule has to balance multiple goals. The following table captures some of the different objectives and metrics, showing how they push the ideal schedule in different directions:

	Marketing	**Manufacturing Operations**	**Quality Control**
Keys to Success	• High or perfect order fulfilment • Agile and effective response to changes in demand • Steady addition of new products • Product freshness and shelf life	• Longer runs with fewer changeovers and cleaning activities • Finished goods inventory buffers • Fewer products • Reduced waste	• Tight process control on intermediate and finished goods products • Product freshness and 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 key to this process.

Limitations of Current Production Planning and Scheduling Solutions

Figure 2: Limitations of Existing Solutions



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

Disconnects between Production Planning and Scheduling

What is planned for many plants today is, in fact, largely infeasible, as 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 cannot take operational realities into account when developing the production plans, optimal efficiency simply won't be achieved.

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 batch process manufacturing environments, these constraints are at the center of the production 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.

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 the required key performance indicators (KPIs).
- 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 an adequate solution for the long haul.

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 use 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.

Inflexible and Insufficient Demand-Driven Solutions

Most detailed scheduling solutions focus on scheduling existing production orders and do not have the ability to take into account changes in material availability, 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.

Solutions which 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 which works for both factory 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—**determining the impact of changes (for example, what would happen if demand were 5 percent greater for Product A or if capacity were 10 percent 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

IBM ILOG Plant PowerOps—A Breakthrough for Planners

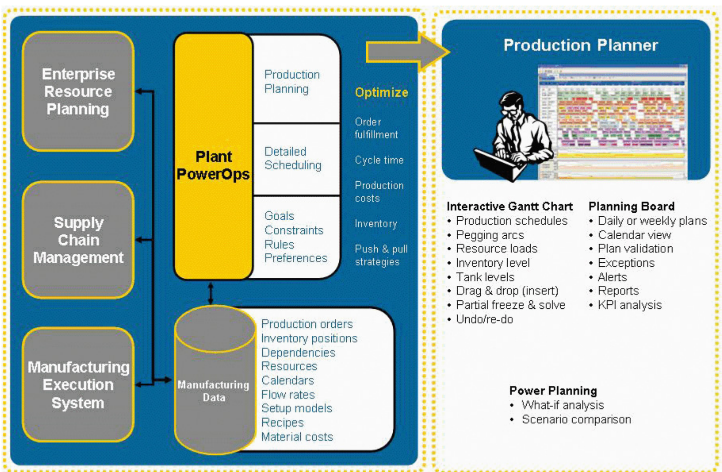
Based on state-of-the-art optimization technology developed over 15 years, IBM® ILOG Plant PowerOps (PPO) is an application specifically designed to meet the planning and scheduling needs of batch process manufacturers. It generates production plans and schedules which maximize:

- **Inventory corridor performance**—keeping finished goods inventories within inventory min/max targets
- **Order fulfillment service levels**—meeting or exceeding levels set for service
- **Throughput**—minimizing changeovers and cleaning events, and maximizing resource utilization
- **Profitability**—increased throughput, more compact schedules and reduced waste

A True Decision-Support System for Planners

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:

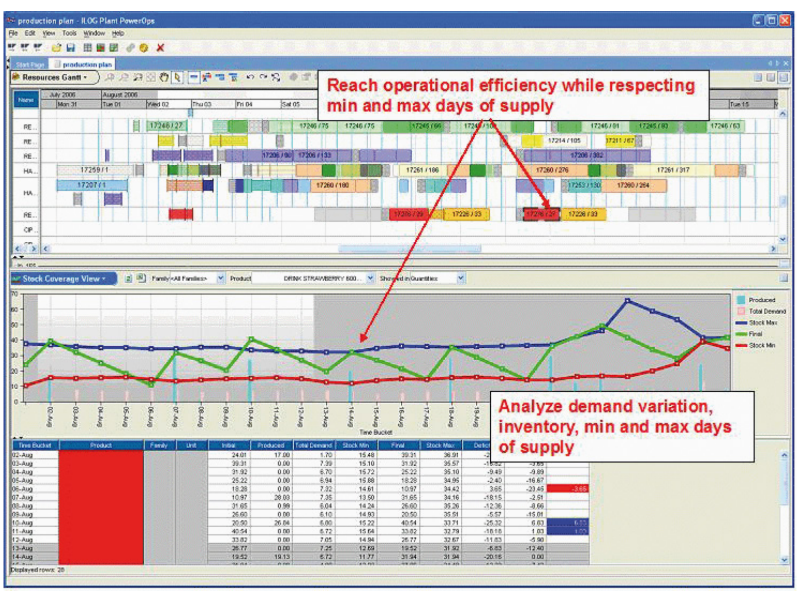
Figure 3: IBM ILOG Plant PowerOps Functionality



The factory 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 versus 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 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. 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. What PPO does better than any other application designed to schedule multiproduct process manufacturing is find the best balance between manufacturing efficiency strategies and demand requirements. If making 10 percent more of one product and 20 percent 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, PPO adjusts the production orders intelligently without jeopardizing manufacturing's ability to fill customers' orders.

Figure 4: 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.

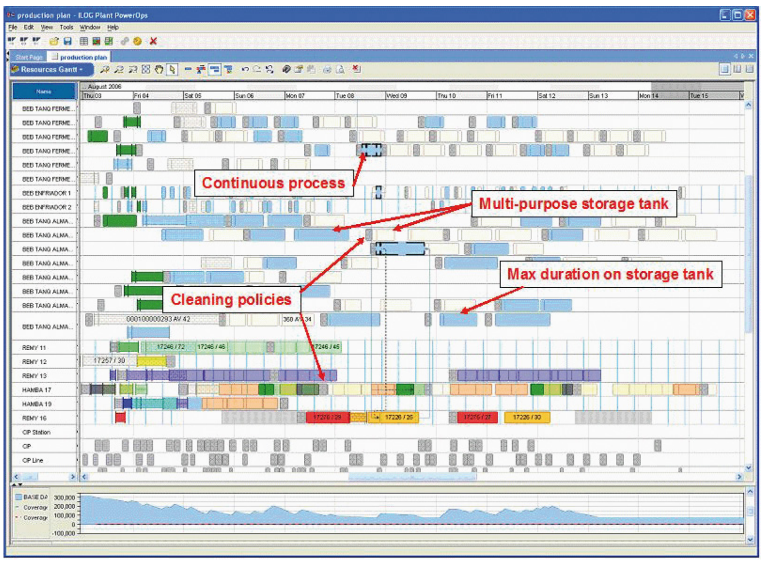
The Gantt chart does more than show details of the production orders on the filling and packaging lines. It is also the main planning board for short-term scheduling decisions: Planners can add, remove, merge, split or move production orders. A sophisticated schedule repair mechanism with a solution 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.

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 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.

Figure 5: Manufacturing constraints that impact a schedule



In this example, 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 must be 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.

Proactive Identification of Potential Bottlenecks—Plant and Process Design

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 there is a manufacturing bottleneck on the packaging line. Does the installation of a new packaging line guarantee increased production? Maybe—maybe not. If installing a new packaging line simply shifts the bottleneck to a different point, for example, intermediate product capacity, the solution is not complete. Using PPO, planners can simulate different plant configurations within a plant and design processes.

Although plant and process design is important in most industries, it is particularly important in the pharmaceutical (especially biotech) and chemical industries. For example, building a biotech plant may take up to eight years and cost several billion dollars. Even a change in an existing plant or process may be expensive and time consuming. Therefore, decisions concerning investments in new facilities or expansion plans, and competing biotech technology have an impact on the long-term profitability of the company. .

PPO is used today by industrial engineers to simulate different plant configurations using a simple user interface. Designed for manufacturing planning and scheduling, it enables engineers to test different plant configurations against alternative future demand trends and find the right balance between cost and manufacturing capacity. It also enables them to discover hidden bottlenecks and make strategic decisions based on realistic simulations of manufacturing schedules.

The ability to use the same tool for plant design and for planning and scheduling production operations has additional advantages. In fact, it allows planners and engineers to work with the same data and make decisions based on the same manufacturing models.

Integrated Planning and Scheduling for Business Performance

Historically, production planning and scheduling teams 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 that are 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 and lost sales. But what are the economics associated with current performance levels? What are the following improvements really worth to a manufacturing plant that makes US $100 million, US $300 million or US $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, PPO can provide more sophisticated economic analysis than what has been possible before. 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, factory 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. PPO can help many process manufacturers improve their supply chain operations while integrating smoothly with SAP R/3, SAP APO, Oracle and other ERP, SCM and MES applications.

An Application Architecture for Planning and Scheduling

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 application 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.

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. IBM is a leader in integration technology, which enables PPO to be integrated with legacy systems using service-oriented architecture (SOA) or with point-to-point integration solutions.

In the next section we describe two integration strategies available to SAP users. Similar strategies and tools exist for many other ERP and SCM systems.

Integrate ILOG PPO with SAP ERP or SCM systems

The IBM WebSphere® Adapter for SAP is a leading SAP integration solution. It is a key part of the Enhanced SAP Connectivity options for the IBM ILOG LogicTools Supply Chain Applications Suite. Two integration options are possible:

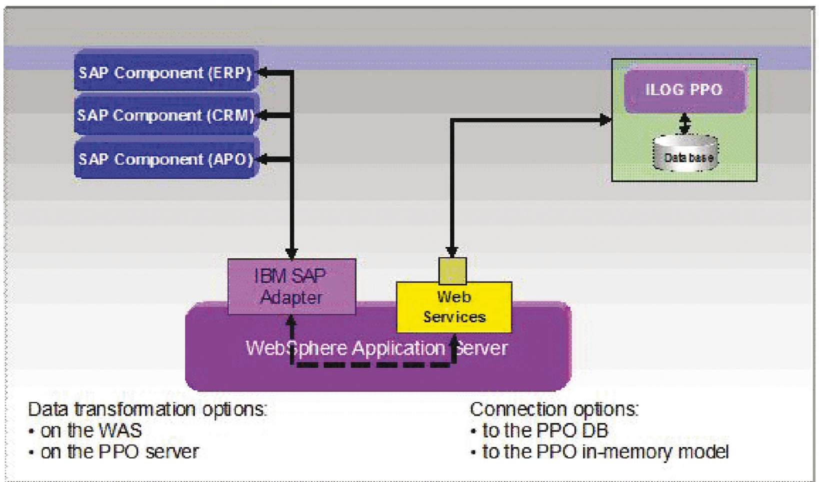
- **Streamlined integration with SAP and PPO:** The IBM WebSphere Adapter for SAP enables bidirectional integration with SAP applications. This JCA resource adapter leverages Java APIs to access BAPI change parameters through RFC and provide the bidirectional exchange.
- **Exploit SOA architecture:** The broker-based integration of SAP and PPO uses IBM WebSphere Service Bus (WESB) or IBM WebSphere Message Broker (WMB). Both products provide strong Enterprise Service Bus (ESB) capabilities to perform powerful routing and transportation needs. Also, WESB and WMB provide powerful development and testing environments. They are based on IBM WebSphere Application Server (WAS), which drives business agility by providing millions of developers and IT architects with an innovative, performance-based foundation to build, reuse, run, integrate and manage SOA applications and services. Additionally, if business process management is required as part of the solution, IBM WebSphere Process Server is available to work within this framework as well. IBM WebSphere Process Server provides industry-leading business process management and integration capabilities, all based on open standards.

The Enhanced SAP Connectivity framework provides the LogicTools SCA suite with seamless integration for SAP. Together with PPO, they comprise a very competitive solution at a very attractive price. By reducing the time and cost of the SAP/ILOG integration, the framework enables IBM to deliver benefits to customers faster, thereby increasing ROI.

Key benefits of this integration strategy include:

- Limited custom development
- Reduced implementation cost and risk
- Facilitated migration to different versions of SAP
- Highly scalable open solution for future enhancements
- Similar technologies for Oracle and other legacy systems

Figure 6: ERP/SCM Integration Architecture



About IBM ILOG LogicTools Supply Chain Applications Suite

IBM's ILOG optimization technology and LogicTools expertise and experience in supply chain management fuel this powerful suite of applications for network design, production sourcing, inventory optimization and transportation planning, in addition to production planning and scheduling. Complement your ERP systems and make better decisions faster to optimize logistics networks and transportation strategies, set safety stock levels for sales and operations planning and improve plant operations in fast-paced industries.

For more information

To learn more about PPO, please contact your IBM marketing representative or IBM Business Partner, or visit the following website: *http://ppo.ilog.com*

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