



**Know the Laws. Use the Tools. Profit.**

## **Managing Supply Chain Risk**

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### ***A Risky World***

In recent years, companies have begun to realize the severity of the risk facing the entire corporation by not addressing supply chain risk. Indeed, more than two-thirds of the companies surveyed by Accenture said they had experienced a supply chain disruption from which they took more than one week to recover (*Manufacturing Business Technology* 2006). Furthermore, the study revealed that 73 percent of the executives surveyed had a major disruption in the past five years. Of these, 36 percent took more than one month to recover. Why does it take companies so long to recover? Why are so many companies susceptible to disruption? Do the new “Advanced Planning and Optimization” systems offer any help? I plan to address these and other issues in this article.

There are at least two reasons why modern supply chains are so susceptible to such disruption: (1) supply chains are not designed with risk in mind and (2) modern planning and scheduling systems and practices are not robust enough to operate under conditions significantly different from those for which they are planned.

### ***“Last Century” Supply Chain Planning***

Although MRP, MRP II and even ERP are now “so last century,” to use my daughter’s favorite phrase, it is useful to see what works and what doesn’t. The goal of these systems has always been to reduce inventory, improve customer service, and to reduce cost by increasing the utilization of expensive equipment and labor. Unfortunately, these systems do not explicitly consider risk and have ignored key facts regarding the processes they try to control.

The first attempts in this area date back to the 1960s beginning with Material Requirements Planning (MRP) that provided material plans with no consideration of capacity. This evolved into Manufacturing Resources Planning (MRP II) which provided some capacity checking modules around the basic MRP functionality. Interestingly, virtually all ERP systems today (including the high end offerings of SAP and Oracle) continue to have the same basic MRP calculations as the core of their production planning offering. Not surprisingly, a recent survey (Burns 2006) showed that users gave low marks to these high end, typically expensive, ERP/SCM systems for performance in distribution and manufacturing (averaging 2.5 and 2.6, respectively, out of 4.0). In a survey performed by Microsoft of mid-sized companies (median revenue of \$21 million, average around \$100 million) 27 percent of 229 companies found their ERP/SCM system to be “ineffective” and 46 percent found it to be only “somewhat effective.” Only three percent found the system used to be “very effective.”

There are two basic problems with these systems: (1) lot sizing is done without consideration of capacity and (2) planning lead times are assumed to be attributes of the part. The first issue results in conservative (i.e., large) lot sizes which increase inventory and reduce responsiveness. The second

issue is similar. Because the planning lead time does not depend on current work in process (WIP) levels and because being late (resulting in poor customer service) is worse than being early (resulting in extra inventory), most systems employ pessimistic (i.e., long) lead times. The result, again, is more inventory and less responsiveness and is especially aggravated when the bill of material is deep.

Efforts to address these problems have gone on for many years. Almost twenty years ago Kanet (1988) described problems with contemporary planning systems that remain today. Consequently, most companies do not run their plants using the output of their ERP/SCM systems but, instead, “massage” the output using ad hoc spreadsheets.

## **21<sup>st</sup> Century Supply Chain Planning Problems**

Obviously, with this kind of “work around” there exists an opportunity to sell more sophisticated software and for some time now there have been numerous offerings. These applications are typically deterministic simulations of the process that assume the demand, inventory, work in process, run rates, setup times, etc. are all known and then seek to generate a schedule that is “optimal” under some specified criteria. One of the earliest of these that was moderately successful is the “Factory Planner” software that has been offered by i2 under various names (e.g., Rhythm) since 1988. Interestingly, the “new” offerings by Oracle and SAP appear to be different only in style and, perhaps, in the level of integration with other data.

Nonetheless, there are at least three problems that prevent the approach of using deterministic simulation from being effective in managing supply chain risk:

1. **The supply chain and plant have inherent randomness** that does not allow for the complete specification of a time for each job with a given labor component at each process center. Such detailed schedules often quickly become out of date because of the intrinsic variability in the system. Moreover detailed schedules do not manage risk which involves random events which may or may not happen. In the past, the disconnect between detailed schedules and the inherent randomness in all processes has been addressed using ever more detailed models requiring ever more computer power. This misses the point. Variability and risk are facts of life and are the result of not only process variation (something that one attempts to control) but also unforeseen events and variability in demand (things that cannot be controlled). At any rate, the result is the same regardless of the variability source. Detailed scheduling can only provide a very short term solution and, in practice, the solution often becomes invalid between the time it is generated and the time that the schedule is distributed and reviewed as part of production planning meetings.
2. **The detailed scheduling system must be re-run often** because of the short term nature of the solution. This becomes cumbersome and time consuming. Moreover, without a method for determining whether a significant change has occurred, oftentimes the schedule is regenerated in response to random noise (e.g., a temporary lull in demand) which is then fed back into the system. Unfortunately, feeding back random noise results in an increase in the variability in the system being controlled (Serman 2000). Because of these problems, many companies have turned off their Advanced Planning and Scheduling systems after spending a great deal of money to install them. One of our own clients, a biopharmaceutical company, shut down its advanced planning and optimization module after trying to manage the massive data collection efforts for “keeping it fed.”
3. **It is impossible to find an optimal schedule.** The scheduling problems addressed are mathematically characterized as “NP-Hard” which means that no algorithm exists that works in “polynomial” time to provide an optimal scheduling solution. The practical result is that for realistic problems faced in modern factories and in the supply chain, there has not been enough time since

the beginning of the universe to find an optimal schedule regardless of the speed of the computer. Consequently, heuristics must be applied to generate a, hopefully, near optimal schedule. *The effectiveness of these heuristics is typically unknown* for a broad range of applications.

The result is that a great deal of computer power is used to create a detailed schedule for a single instance that will never happen (i.e., the random “sample path” will never be what is predicted a priori) and the schedule becomes obsolete as soon as something unanticipated occurs. Effectively, detailed schedules never reflect current conditions.

The most advanced systems today offer two methods of planning for manufacturing supply chains: (1) “what-if” analysis using a deterministic simulation of the supply chain and (2) “optimization” of a set of “penalties” (again, using a deterministic simulation) associated with inventory, on-time delivery, setups, and wasted capacity.

In addition to the fundamental problems listed above there are two practical problems with this approach: (1) what-if analysis is tedious and (2) optimizing a penalty function is not intuitive.

The tediousness of what-if analysis comes from all the detail that must be considered. Figure 1 shows the output of a typical APO application. The graph shows the scheduled production on six machines in one factory along with projected inventory plot of one of the items produced. The planner can move jobs in the schedule and drill down on other items to view inventory projections. While this level of integration is impressive, it is not particularly useful especially when there are hundreds of machines (not to mention labor) to consider along with thousands of individual items, each with their own demand.

Likewise, the use of “penalties” to determine an “optimal” schedule is not intuitive. What should the penalty be for carrying additional inventory? What is the cost of a late order? What are the savings generated by reducing the number of setups, particularly if there is no reduction in head count? What is the cost of having idle machines? Penalties such as these are, at best, an estimate and the source of endless internal wrangling between production and accounting.

Thus, there is currently a huge gap between what is needed and what is offered. Described below is the means to combine existing technology with new technology that can address all of these issues without the tediousness or the complexity of modern APO systems.

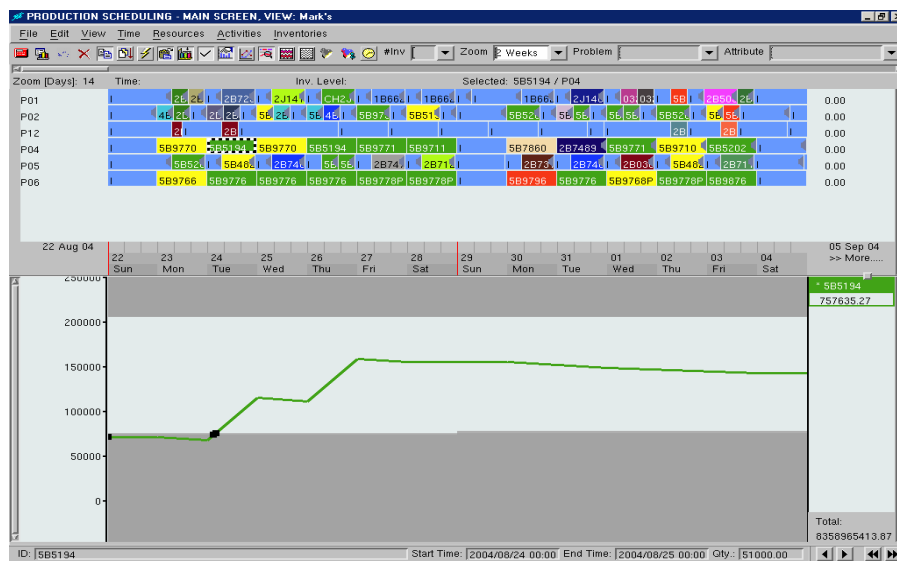


Figure 1: Output of APO application showing a production schedule and inventory

## **Factory Physics® Principles and Advanced Supply Chain Solutions**

Hopefully, we have begun to realize that the solution to business problems is *not always more information technology!* Instead of faster computers and more integration, we need to make *a fundamental change in the way we manage manufacturing supply chains.*

Before that, one must understand how manufacturing supply chains work and there is no better way to do this than to review of some basic **Factory Physics** principles. These principles describe how *all* manufacturing supply chains work beginning with the fact that all manufacturing supply chains consist of only two essential elements: **Demand** and **Transformation**. Without Demand, there would be no market for our goods. If there was no need for Transformation, those demanding the goods could find them laying about (e.g. people have demand for air everyday but there is no business providing that air).

Likewise, in any manufacturing supply chain there are two primitive components: **Stocks** and **Flows**. The Flows represent both the Transformation element (an out flow) and the Demand element (an in flow). The Stocks provide a means to separate and coordinate these two Flows.

In a perfect world, Transformation would exactly meet Demand. This means that there would be perfect processes (producing exactly what is needed) and perfect customers (purchasing exactly what is produced when it is produced). But, because there is variability, this perfect world cannot exist. Therefore, a Factory Physics Law states that in order to link Transformation and Demand, one or more buffers are required and the more variability there is the more of a buffer will be needed. While a Stock is one way to match Demand to Transformation, there are two others: (1) extra time and (2) extra capacity. Thus, another Factory Physics Law is that there are three and only three possible **buffers** to interface between Demand and Transformation: **inventory, time, and capacity**. In other words, the Transformation can satisfy Demand in several ways: (1) immediately from Stock, (2) by making the Demand wait for the product, or (3) by maintaining extra capacity in order to provide timely production upon demand. Thus, effective risk management is, essentially, a matter of effective buffer deployment. *Determining an optimal portfolio of buffers* means determining how much risk to take on and, given that risk, determining how best to buffer it whether it is extra inventory, extra time to satisfy the customer, or extra capacity to have available to cover disruptions. Unfortunately, there is no one answer to this problem. The optimal configuration of risk and buffers will be very different for different business situations. The aspirin operations of Bayer Corporation and the computer factory of Dell Corporation have very different configurations. Bayer is likely to have a considerable amount of inventory with little excess capacity (to keep costs down). Conversely, Dell has *no* finished goods inventory and a significant amount of extra installed capacity. How else could Dell build custom computers in a timely way when there are peaks in demand at Christmas and at the beginning of the school year? Neither of these situations uses a significant *time buffer* but the Moog Corporation, a supplier of custom servo-valves to high-tech and aerospace customers, requires a time buffer to create a customized product.

It is also important to note that a *flexible buffer* is less costly than a permanent one. This is why *postponement*, the ability to delay committing a common component into the final product until the last possible moment, is effective in reducing both the inventory and the time buffers. Likewise, having a flexible capacity buffer such as the “make-up” shift used by Toyota or temporary workers that can be called upon when demand is higher than normal, is less costly than employing all the workers all the time. Furthermore, quoting due dates with variable lead times is more effective than stating a constant lead time.

So how do we use this understanding to create a system that can (1) accommodate risk (2) provide a method for effective planning and control, and (3) does not “lose the forest for the trees” (while retaining the ability to see a particular “tree” if the need arises)? Key to creating such a system is to replace our thinking of points in time when particular jobs finish at particular stations with a way to think about the *flow* of jobs through the system. Smooth and continuous flow has been the essence of the Toyota production system—though we are not advocating everyone try and be like Toyota. Achieving flow does not require that one duplicate what Toyota has done in automotive assembly. If we can achieve flow, then planning and controlling production become easy. Then, instead of attempting to schedule hundreds of individual jobs on a Gantt chart or trying to specify artificial penalties in an APO, a planner would use a few basic measures and controls to manage the *flow*.

Figure 2 shows a “supply chain segment” and indicates all three buffers: time (customer lead time or backorder time), inventory (between transformation and demand), and capacity (anything greater than demand). The flow in figure 2 is a simple linear flow but it could contain several levels and many routings. The stock contains either jobs that complete before their due date in the case of make-to-order or of finished goods inventory in the case of make-to-stock. Coming from the left are two arrows indicating make-to-order demand and raw materials. These materials would be supplied by a previous supply chain segment. From the right comes an arrow showing make-to-stock demand.

We can take this simple framework and create a new and more effective way to manage manufacturing supply chains. The key to this is to reduce the number of values that must be monitored as well as control variables in the problem. This means that **instead of providing a detailed schedule indicating where each job is scheduled on a machine during a given time slice, we determine a set of control variables that will dynamically and automatically determine the schedule as the system evolves.** We call this approach, “Dynamic Risk-based Planning and Scheduling” or DRPS. Under DRPS we need only monitor projected inventory and projected service levels and then control a few key parameters—reorder points and/or lead times, production quantities (lot sizes), installed capacity, “make-up” capacity, WIP level and the *virtual queue*.

A brief reflection on the design of the system will show that if we have optimized the planning parameters listed above, the entire system will run well so long as projected service and inventory levels stay within acceptable ranges. Lot sizes have been established that minimize WIP and finished goods subject to the available capacity. Lead times (and/or re-order points) are set by considering the tradeoffs between service and inventory levels. Thus, jobs can move through the flow in a “first in system first out” (FISFO) order without the need for a detailed schedule. Safety stocks are set considering the time in the virtual queue plus the time through the flow and with regard to the error in our forecast. Thus, once these parameters are set (reviewed periodically perhaps once per month), the planner need only monitor the projected inventory and service levels. The only time action is required is when these levels exceed set **trigger points**.

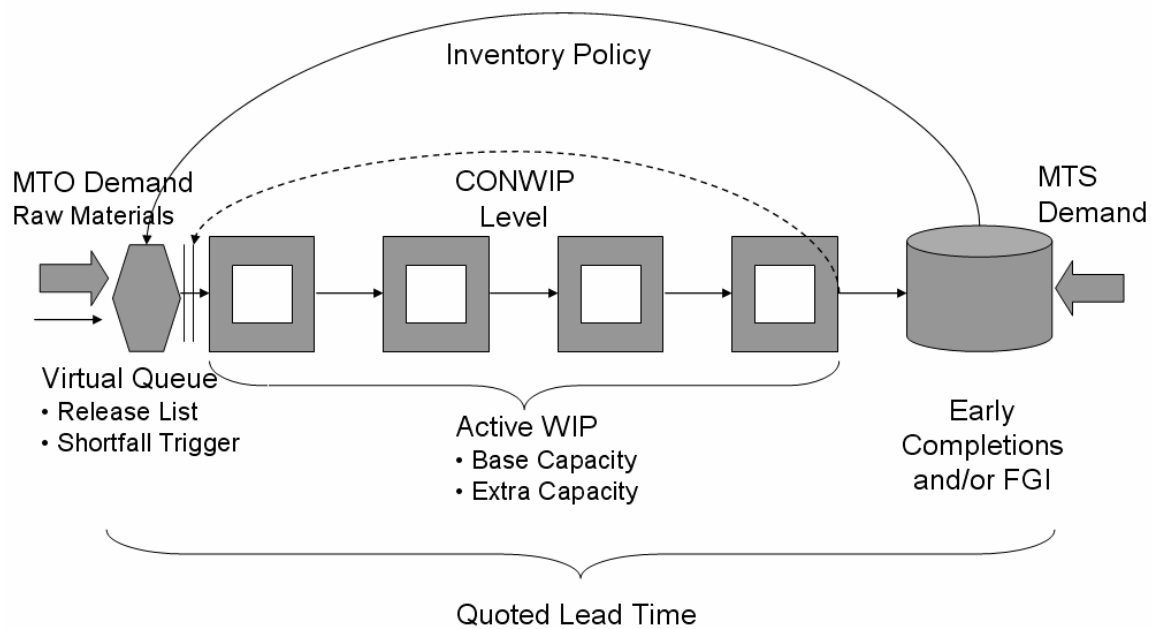


Figure 2: A Make-to-order CONWIP line.

These trigger points take two forms: (1) indicating insufficient capacity and (2) indicating more capacity than is needed. If the virtual queue grows beyond what is planned for in the lead times, there is insufficient capacity and so the “extra capacity” (e.g., overtime, make-up shift, etc.) is applied. If the virtual queue becomes too low, one can either reduce capacity or pull in some jobs early. The result is not only a much simpler supply chain to manage but one that can automatically respond to random changes in demand and supply **without the need to reschedule**. This ability to automatically adjust is a tremendous improvement and makes DRPS more effective than the more complex APO. Table 1 compares Dynamic Risk-based Planning and Scheduling with APO in this regard.

Situation	ERP APO	DRPS
Capacity greater than expected.	Cannot work ahead of generated schedule.	Can work ahead up to defined earliest release dates.
Capacity less than expected.	Schedule becomes increasingly infeasible, orders become late unless high safety lead time.	“Shortfall trigger” indicates need for additional capacity. Do not need high safety lead time.
Demand greater than expected	Shortages unless very high safety stock	Shortfall trigger indicates need for additional capacity; no shortages, minimal safety stock.
Demand less than expected	Unneeded orders released; inventory rises	No unneeded orders released; inventory stays in planned range

Table 1: Situational comparison of APO and DRPS

Once these parameters (reorder points and/or lead times, production quantities (lot sizes), installed capacity, “make-up” capacity, WIP level and the *virtual queue*.) are known, we are ready to implement the system. Fortunately, we can do this relatively easily using the existing MRP system and a generalized pull system known as CONWIP.

## CONWIP

The CONWIP pull protocol is a method for achieving pull production in a wide range of production environments (see Spearman, et al., (1990) and Hopp and Spearman (2000)) and is key to flow management. This mechanism maintains a nearly constant level of WIP that is needed to keep bottleneck processes busy by starting a new job only when the WIP level has fallen below a given maximum level. The relation between throughput (output), WIP, and cycle time is seen in figure 3. The result is predictable cycle times, smoother flow, and higher throughput than would be seen in an equivalent push (e.g., MRP) system. The CONWIP mechanism also isolates the variability inherent in demand from disturbing the flow. This is accomplished using the virtual queue. If demand goes up, WIP does not but the virtual queue does and the projected service levels begin to fall. Likewise if demand begins to fall, the virtual queue falls but WIP stays constant and projected inventory levels begin to rise.

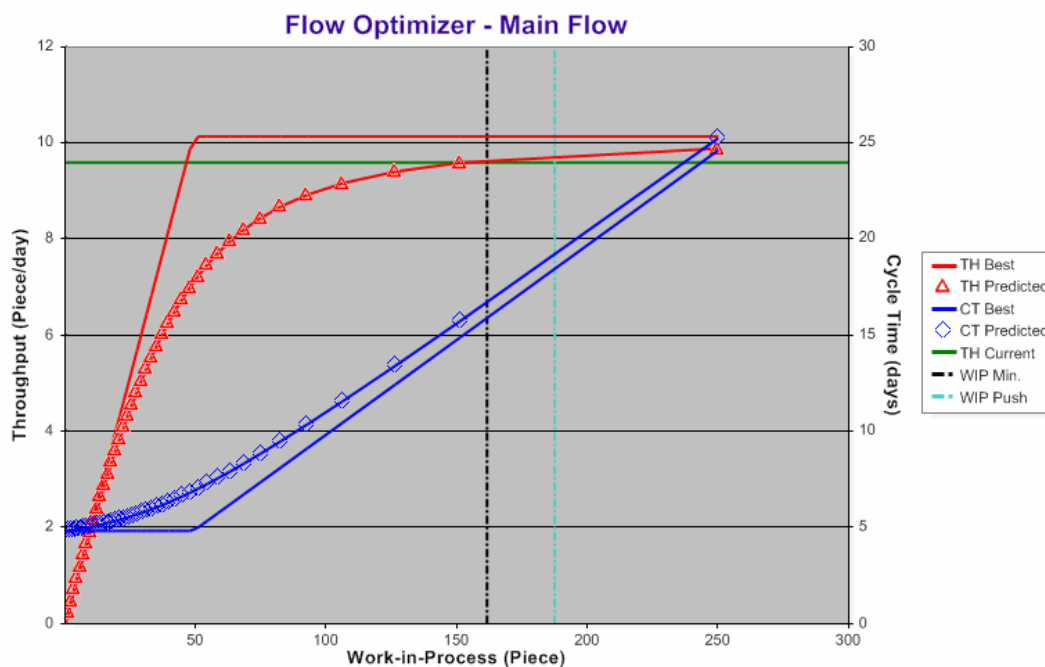


Figure 3: WIP, Demand, Throughput, and Cycle Time shown on Factory Physics Inc.’s Flow Optimizer

## Using MRP with Pull

First, it is important to note that the plans generated by good old-fashioned MRP can be quite good if several conditions hold:

1. Average demand does not exceed capacity.
2. Jobs are released using a pull system that prevents WIP explosions.

3. Cycle times are short enough to avoid expediting.
4. Safety stock (or safety lead time) are determined considering demand and capacity.
5. Batch sizes are determined considering demand and capacity to ensure minimal WIP and low inventories.
6. Due dates are checked by considering the characteristics of the pull system and the sequence of the jobs to be pulled.

If we have designed the system well, these conditions will hold. We use MRP in the usual way but instead of starting jobs according to MRP's "planned order release" list, we pull them in using the CONWIP protocol. The entire release list becomes the virtual queue. Then, knowing the cycle time of the line and the rate at which jobs are being pulled into the line, we can accurately predict when each job will complete.

## Conclusions

We have seen that neither traditional systems such as MRP nor modern systems like APO adequately address risk issues. It is also apparent that more IT is not the solution to the problem without completely rethinking the problem. What we need is a system that is *dynamic* to avoid rescheduling, *risk-based* to accommodate risk factors and randomness, and that links *planning* and *execution*.

The steps to implement are:

1. Use appropriate, risk-based models to optimize MRP planning parameters: lot size, planned lead times, and safety stock levels.
2. Use MRP to perform netting, BOM explosions, and generate a job release pool.
3. Quote lead times using the position in the virtual queue and cycle time in the CONWIP line.
4. Use a CONWIP system to pull from job release pool into shop.
5. Use FISFO (first-in-system-first-out) for prioritization in the line.
6. Monitor the virtual queue to indicate when extra capacity is needed.

Factory Physics Inc. is the leader in offering software and training to enable Dynamic Risk-Based Planning and Scheduling. If you'd like to get a benchmark of your organization's performance, improve on-time delivery and profitability or find out more about the power of Factory Physics principles and software, email us today at [info@factoryphysics.com](mailto:info@factoryphysics.com).

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