Successful navigation of uncharted territory

Coping with moveable bottlenecks in discrete manufacturing

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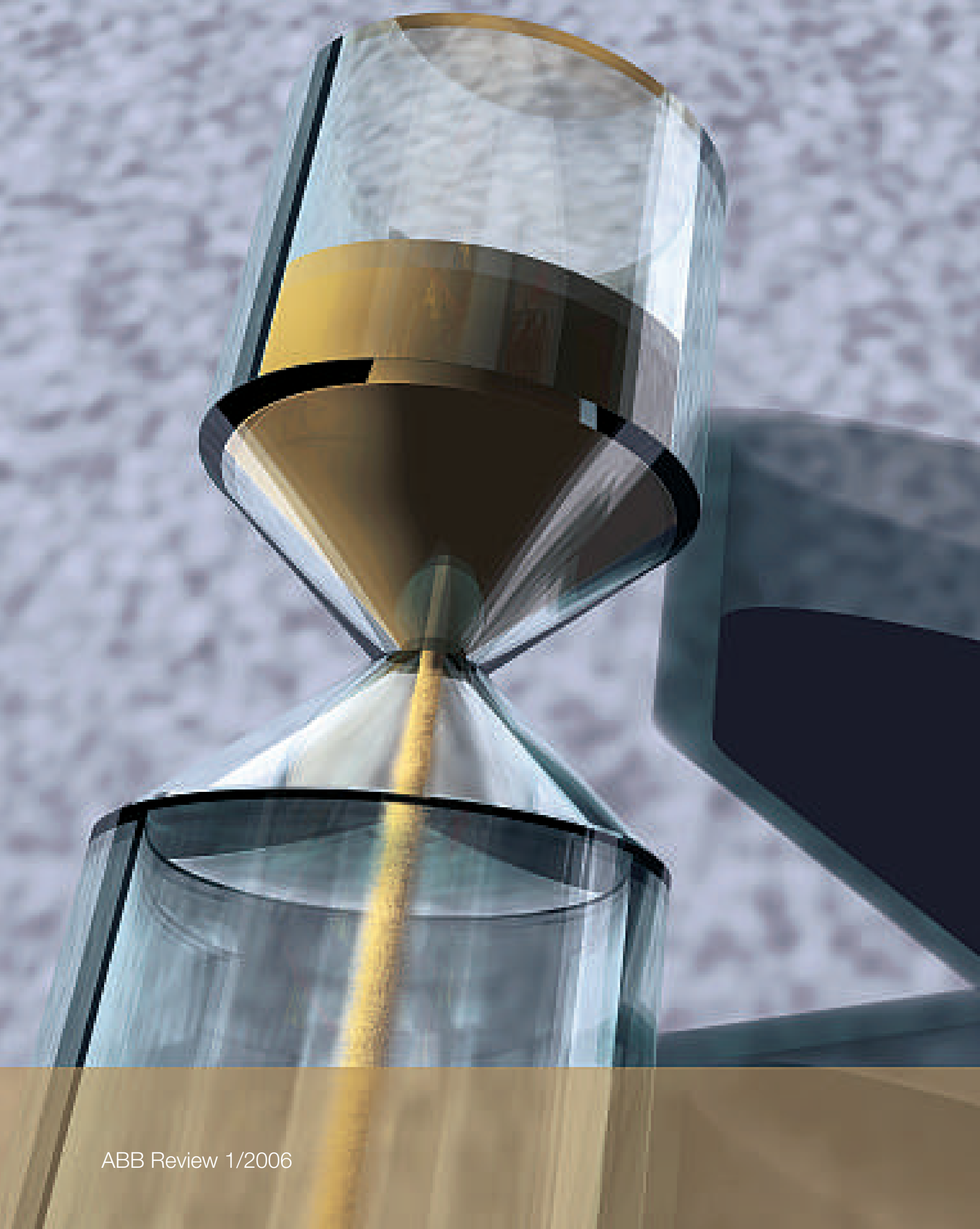

It is often heard that time is money. This is certainly true for Supply Chains. A swift throughput implies not only fast delivery, but also high productivity as resources are freed quickly. In analogy to a sand-glass where the neck constrains the sand flow, the slowest stage of a Supply Chain limits overall throughput. Just as the glass does not function without sand, the Supply Chain slows unnecessarily when its bottleneck runs below capacity. Strategies exist to prevent this, but for most of these the bottleneck is a single production stage. What happens if the bottleneck shifts between stages due to product variability?

To improve advanced planning and scheduling at the production Supply Chain of ABB's transformer plant in Zaragoza, Spain, a planning tool called DIVINER 3.0 has been developed to manage moving bottlenecks. It uses the order backlog to predict the future evolution of the production Supply Chain, anticipating changes instead of reacting to them when they occur.

Demand driven manufacturing

When a production line builds customized variants, the challenge of effectively handling Supply Chain bottlenecks grows if, instead of always manifesting itself in the same process stage, the bottleneck shifts from one stage to another. The associated control problem becomes highly dynamic and difficult to solve efficiently. Reformulating the dynamic problem as a sequence of fixed bottleneck solutions has resulted in major performance improvements at ABB's transformer plant in Zaragoza, Spain.

The importance of accurate scheduling

A strategy for accurate scheduling of the entire manufacturing Supply Chain must synchronize the entire workflow, stretching from suppliers through manufacturers to wholesalers. The end-customer can be given an accurate and reliable date of delivery.

An optimized schedule not only provides precise completion dates for each production phase but also uses these to tighten the flow along the whole chain.

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Not such a simple world

Discrete manufacturing is a broad field in which challenges vary broadly from one industry to another. At the extremes are mass-manufactured consumer goods, where large quantities of identical products are produced, and for example, shipbuilding, where it is rare for even two fully identical ships to be commissioned. ABB's Zaragoza plant has a mixture of these two concepts leading to a hybrid environment. Discrete manufacturing can be divided roughly into two categories:

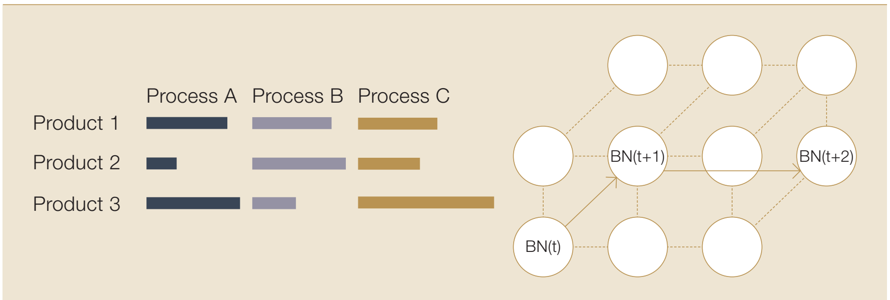
- *Mass production* (make to stock): High efficiency and low costs are a "must". The "make to stock" model disconnects the production rhythm from market fluctuation. This is especially the case for consumer goods, where the customer expects a very short lead-time from ordering to delivery. Normally, production volumes are very large, with long production series of the same product and short cycle times. The uniformity of production means that the bottleneck always occurs in the same place. This high predictability is reflected in the optimization strategy. A lean Supply Chain is the key market qualifier[1] for this style of production (especially on the European market). The principal remaining variability is the natural randomness (quality rejections, breakdowns, failures, sick leaves, delays etc), which can be absorbed by a relatively small buffer.
- *Custom production* (make to order): Products are designed to order and this customization causes inherent variability. Besides the same omnipresent non-deterministic variability that effects mass-production, further variability is caused by customer specifications. The production bottleneck and cycle times are order-dependent and therefore variable. An agile Supply Chain is the key element for being successful in this type of market.

Can these two strategies be successfully combined so that custom production can be reduced to the variability of mass production? Can a line be both agile and lean?

To answer this question, one should consider the model for managing complex, highly variable environments using the Theory of Constraints (TOC) Textbox on next page. It is observed that in each process with interdependent events, there is always one point with the lowest throughput. This bottleneck determines the production rate of the whole process. If the bottleneck is fixed, it can be used as the control point. In this case, the rules and links between processes do not change with time. CONWIP[2] and CONLOAD[3] are examples of this type of control philosophy. In such a case, pull signals[4] (typically using cards) control the flow in the system.

These approaches focus on systems with a fixed bottleneck. From the point of view of traditional production technology the moveable bottleneck problem is uncharted territory; the solution requires original thinking. One significant difference between a "make to stock" philosophy and a design to order one is that a variant defined by a customer specification can feature in the latter, leading to "non-standard" production. Such customized products will have different cycle times per operation.

1 Multi-project job shop environment with moving bottleneck as a result of product and process variability



Footnotes

1) The key market qualifier is a resource that, at a minimum, every company must have to compete in a given market.

2) CONWIP (CONstant Work In Progress) is a line-scheduling strategy in which a new job is allowed to enter the line whenever an older one leaves, or more generally, the number of jobs in progress is kept below a defined threshold.

3) CONLOAD (CONstant LOAD) is a refinement of Conwip that additionally takes into account processing times.

4) A pull signal is a signal that requests the replacement of an exhausted resource.

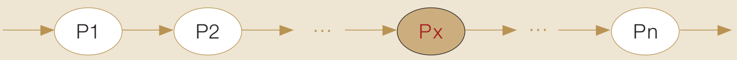
In such a multi-project environment where a large number of different units are produced, a shifting of the bottleneck over time is likely if the variability of products is sufficiently high. This is the case at the Zaragoza plant 1.

One way to avoid movement of the bottleneck is to over-dimension every process. This over-dimensioning is called protective capacity. It is a simple but costly mechanism for transforming dynamic bottlenecks into fixed ones, thereby permitting a single control point. However, this approach requires a larger-than-needed investment. The protective capacity acts as a buffer against variation, but as with any inventory, not all features of excess capacity are beneficiary. The optimal dimension (and affordability) of the protective capacity must be determined.

The size of the protective capacity will depend on the variability of the process. The greater the variability, the more excess capacity will be required. A "design to order" manufacturer wishing to adopt a make to stock control strategy could use this approach. Depending on the customer specification, some processes may be

How to control the chain with TOC

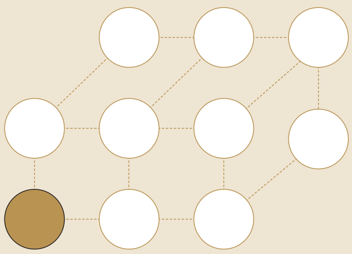
In every system composed of individual processes there is always one process with the smallest capacity. In other words, this process will be the slowest of the chain, and have the longest cycle time.



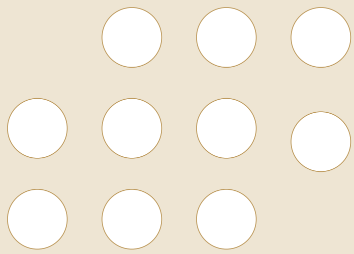
The throughput of the whole system is determined by the slowest process (Px), marking the tact cycle of the output. Px is called the bottleneck, acting as the constraint of the complete flow.

The Theory of Constraints (TOC developed by Eliyahu Goldratt) focuses the control of the system on the bottleneck. Since the output is limited by the slowest process, the other processes should depend on the bottleneck to avoid any inefficient stock between process stages. In other words, the bottleneck is the master process dominating the flow.

The dependences between Px and the other processes are used to permit the whole system to be controlled by acting only over Px. It is much easier to control the complete system focusing on one point, than having to deal with a more complicated one with many degrees of freedom.



One point to control the system

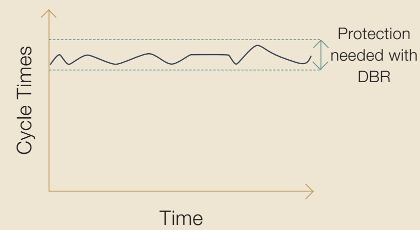


More than one point needed to control the system

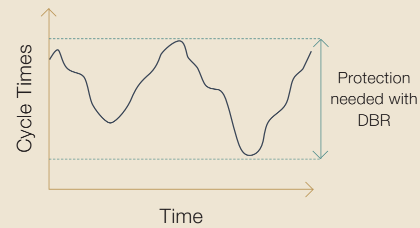
In this way, there are five steps in TOC showing how the chain should be controlled in order to obtain best operation:
1. Identify the bottleneck (BN) in the System.
2. Decide how to exploit it.
3. Subordinate the other processes to the BN.
4. Try to remove the BN.
5. If the BN is removed, return to step 1.

Px is protected by buffers immediately preceeding it trying to avoid any starvation of the bottleneck. If Px is stopped, then the output will be directly reduced. All other buffering is unnecessary. In the same way, in a project management strategy, buffers (time) protect the processes belonging to the critical chain.

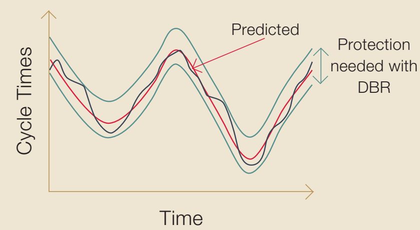
2 Required protection with DBR for standard processes with natural variability



3 Required protection with DBR for design-to-order processes with changes in product mix



4 Required protection with Diviner for design-to-order processes with changes in product mix and natural variability



Demand driven manufacturing

overloaded with one product while others are running below capacity with another.

Essentially, over-dimensioned buffers reduce the interdependency of sub-processes. Some companies are faced with process cycle times whose average value is similar to their standard deviation. The correlation coefficient between processes is around 0.3–0.4. This shows that the processes within the system are almost independent. In such cases, a huge protective capacity is necessary to keep the bottleneck in the same place (more than 25 percent of the perfectly balanced capacity). Bitter facts, indeed! There is, however, another solution.

DIVINER 3.0 analyses the variability resulting from the product mix in backlog and uses this to optimize the future behavior of the system using discrete-event simulation.

This solution makes use of the fact that the variability is not totally random. A "make to order" factory has an order backlog that it can use as planning data. In this way, the protective capacity can be divided into its two component parts: the basic "make to stock" style capacity 2, and the additional "make to order" style component 3 resulting from customer specification variability 4.

An important market qualifier in Europe is the price. There are considerable rewards for reducing protective capacity. Can such reduction be safely achieved in this type of environment?

Advanced control with DIVINER 3.0.
An analogy can be drawn between the pull methods based on a fixed bottleneck strategy (eg, CONWIP, CONLOAD) and a typical control system diagram. Because the Pull production control reacts to discrete events (a part is produced, a buffer is built up or emptied, etc), the feedback of the system is computed from the signal of the previous step. The resulting analogy is shown in 5.

As the variability of the cycle times can in part be studied in advance once the customer specification is available, these data can be used to predict the behavior of the system. Such a strategy is proactive instead of reactive. Moreover, since the bottleneck is dependent on customer specifications, the cycle times of the orders in backlog can be computed and a prediction of the location of the bottleneck is possible. The discrete-event system simulation is the basis of a tool used for predicting the behavior of a system. With these ideas in mind, a possible control diagram is shown in 6.

This strategy is the basis of a predictive control in production. A movable bottleneck would be dealt with by trying to act before events happen: Supposing the bottleneck is in process A, but it is known that it will move to process B; process B could continue working at high volume to exploit the future bottleneck to the maximum. Such a buffer management philosophy not only focuses on the current bottleneck, but also on future ones. Such solutions can be obtained using a predictive control analogous to that of advanced automatic systems combining feedforward terms with feedback information.

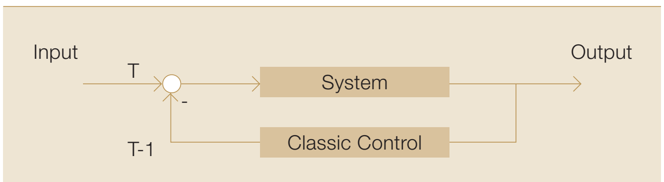
This approach leads to a minimization of costs because:
- The control system is proactive, instead of reactive (as it would be in DBR[5]): Remedial actions are taken before problems occur, making interventions less costly.
- The protective capacity can be reduced, allowing the bottleneck to move and thereby reduce the excess cost as well.

The Zaragoza plant has reduced its TTPT (Total Throughput Time), from order to shipping, almost by half.

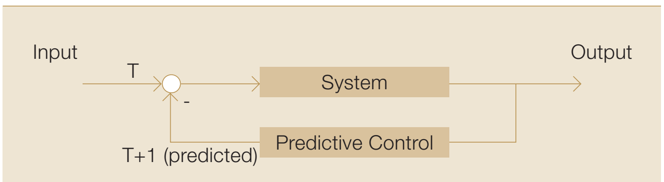
DIVINER 3.0 analyses the variability resulting from the product mix in backlog and uses this to optimize the future behavior of the system using discrete-event simulation. Buffering

Footnote
[5] DBR: Drum-Buffer-Rope is an expression for the application of TOC to scheduling. The "drum" represents the bottleneck that can draw work into the system by the "rope", so keeping inventory to a minimum. There is only one area of queuing, and that is the monitored "buffer" in front of the bottleneck that protects this from adverse effects such as unreliable suppliers, employee absence and last minute customer requests.

5 Analogy from automation system for PULL production control model



6 Proactive model of control with application to manufacturing system



limits are reduced to their minima while still protecting the system against (only) the natural variability of standard mass production 4. The resulting protective capacity is lower than would be expected with DBR.

The theory sounds most attractive. In practice, many enticing theories fail to deliver usable results because they cannot be applied in real-world production environments. The best part of this theory is that the applicability is fully supported by line performance results from the Zaragoza factory since the start of the project in 1999.

Success along the line

The best way to evaluate the result of the application of this strategy is to look at the most representative KPIs (Key Performance Indicators) associated with its performance:

The Zaragoza plant has reduced its TTPT (Total Throughput Time)[6)], from order to shipping, almost by half. Today it is 48 percent lower than in 1999 7.

Production TPT (Throughput Time)[6)] has been reduced to only 29 percent of 1999s level 8. Today on-time-delivery of transformers is 96 percent against 70 percent in 1999 9. The plant's production volume has grown by 245 percent since 1999.

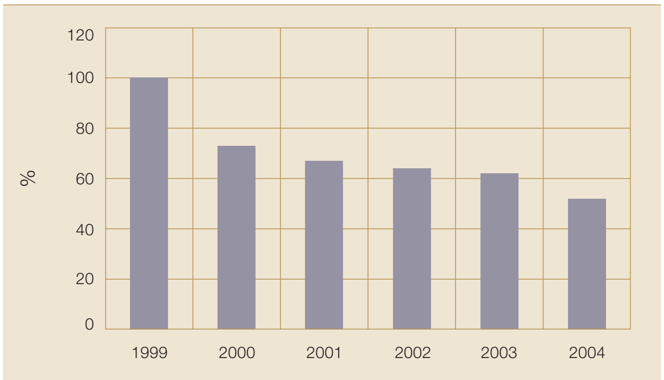
Production transformed

The most important conclusion, and perhaps also the most profound one that the team at the Zaragoza plant has learnt is that if an organization feels something must change, then fear of the unknown is not the best advisor.

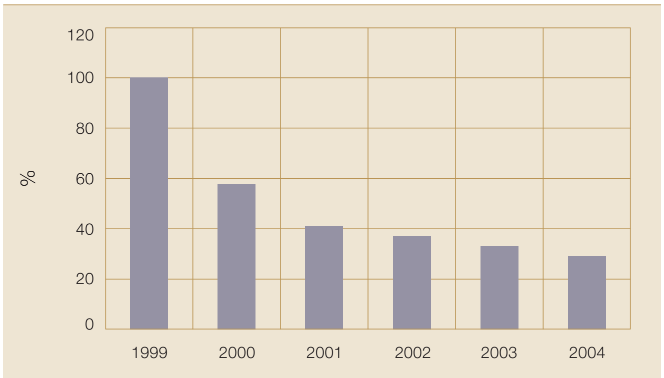
Footnote

[6)] see glossary on page 74

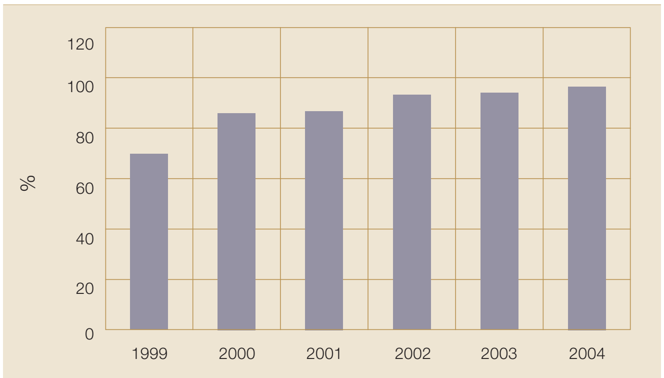
7 Total throughput time (TTPT) was reduced by almost half



8 Production throughput time (TPT) has been reduced to 29 percent of its 1999 level



9 Better scheduling leads to better on-time-delivery



The Zaragoza team had to face a serious challenge to remain competitive in a very complex environment. It showed how the limits that were thought to be absolute could be overcome.

These results have demonstrated that it is possible to control a Supply Chain with a movable bottleneck and, moreover, that this is the right method to cope with high variability productive systems while keeping costs low (agile and lean) by avoiding protective overcapacity.

This effort was recognized in 2005 by both of Spain's most prestigious logistic innovation awards: The Pilot Award and CEL Award (granted by the Spanish Logistics Centre, Spanish member of the European Logistics Association).

ABB's Zaragoza factory has gained a very high reputation among its customers. This could be achieved only through the combination of a customer-centric approach, a continuous improvement attitude and the openness to innovative solutions for Supply Chain planning and scheduling.

The navigating of uncharted waters needs courage and imagination.

Asking questions that go against the grain of common practice and the courage to break out of the mold – sometimes even transgressing perceived theoretical limits – are the best tools for achieving improvements. They foster the spirit of continuous improvement and reward the persistence that bears fruit, leading to better solutions and broader competence.

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