Parametric Factory Simulation for the Responsive Enterprise

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ABSTRACT

Simulation offers a powerful way to investigate the boundaries of what can be achieved by a manufacturing system, demonstrating the impact of schedules and policy decisions such as the placement of buffers and the size of safety stocks. Unfortunately, the construction of factory models at the necessary level of detail is a time-consuming process, requiring specialist skills.

This paper describes a novel approach to the representation of logistic control within a simulated factory, and its implementation in a study of a business unit at Volvo Aero in Trollhättan, Sweden. Several innovative features were built into the model, making it possible for users who were not simulation experts to explore a broad range of scenarios. The resulting model architecture, as described in this paper, takes simulation out of the computer lab and places it in the hands of managers, as an enabler of the responsive enterprise.

Keywords: Parametric simulation, logistic control, kanban, aerospace

INTRODUCTION

Simulation allows the performance of a system to be investigated, using a model so that the real-world facility is not disturbed. If a suitable replica of a business unit can be created, many situations can be investigated, and planners can experiment with system parameters to increase confidence in the promises they make to customers, reduce tied-up capital, or increase throughput.

The case study used in our investigation was a Volvo Aero business unit that produces two kinds of Turbine Exhaust Casing (TEC). These are a relatively large engine component, with intricate features that must be produced by casting or fabrication, plus a considerable amount of machining. The facility is operated as a focused factory; originally advocated by Skinner [1], a focused factory concentrates upon a limited set of products in order to avoid the contradictions and compromises introduced when trying to bid for every business opportunity. The two TECs that are made here are for the International Aero Engines V2500 (as used in aircraft such as the Airbus A320 family) and the Pratt &

Whitney 2000 (Boeing 757 and C17 Globemaster). Production volumes for the two types differ although the methods are broadly similar.

The market for aero engines is unusual in a number of ways, combining high value products, low volume, a long product lifecycle and a lengthy support requirement in the aftermarket. It is also a market that has exhibited sudden changes in response to oil price increases, health scares, wars and terrorism [2], while further complications are introduced by the behaviour of airlines, including usage patterns, the desire to standardise equipment within fleets, and a lively trade in used aircraft. The net result is that demand patterns are variable and difficult to predict.

It was not sought to 'optimise' the manufacturing system in any simple sense. It was felt that any attempt to produce an ideal solution would simply produce a fragile one that could not be exposed to the reality of the aerospace value chain. As Ingalls [3] observed, variability makes optimisation impractical, whether arising from demand forecast variance, supply reliability, or the quality of incoming material. All of these were issues that could eventually be explored via the simulation that was developed, but the goal was not to find optimal parameters, given how much the focused factory is at the mercy of external events. Thus, any attempt to produce a better system would require a tradeoff between a number of goals, including leanness and delivery performance.

Although the requirement for TECs can fluctuate, the period when the study was conducted was one of strong growth in demand, and it was desired to explore the possibility of increasing the throughput of the facility, if possible. Much of the production equipment is very expensive, so any solution that required machines to be duplicated would have introduced a cost burden to be borne during periods of low demand. However, bottleneck machines are already operating on multiple shifts, so any improvement in the throughput or on-time delivery performance of the focused factory would have to come about through improved logistic control. A simulation was constructed to explore the alternatives available.

MODEL CONSTRUCTION

Arena from Rockwell Software was selected for the construction of the simulation. Whereas many of the more modern tools attempt to reproduce a layout of the facility under study, Arena uses a flowchart paradigm, where each entity is an event rather than a work centre. This matched the 'Operations Flow Diagram' that was used at Volvo Aero to illustrate the process plan for each TEC (Figure 1). It was desired that the layout of the Arena model should resemble this layout as far as possible, because a strong correlation between the model and Volvo Aero's documentation would be helpful in obtaining 'buy-in', and eliciting comments from staff.

Historical data had been gathered from the beginning of 2004 onwards, recording the time and date when each workpiece had left each production stage. The launch dates for raw materials and the completion dates for finished goods were also known. Analysis of these historical data revealed that the duration of most operations could be expressed as a triangular distribution, representing natural variability in processing times, taking into account the incidence of minor problems. Major problems that caused a workpiece to be taken out of the manufacturing sequence formed a 'tail' on some distributions; these were handled separately so that the impact of quality problems could be investigated in closer detail.

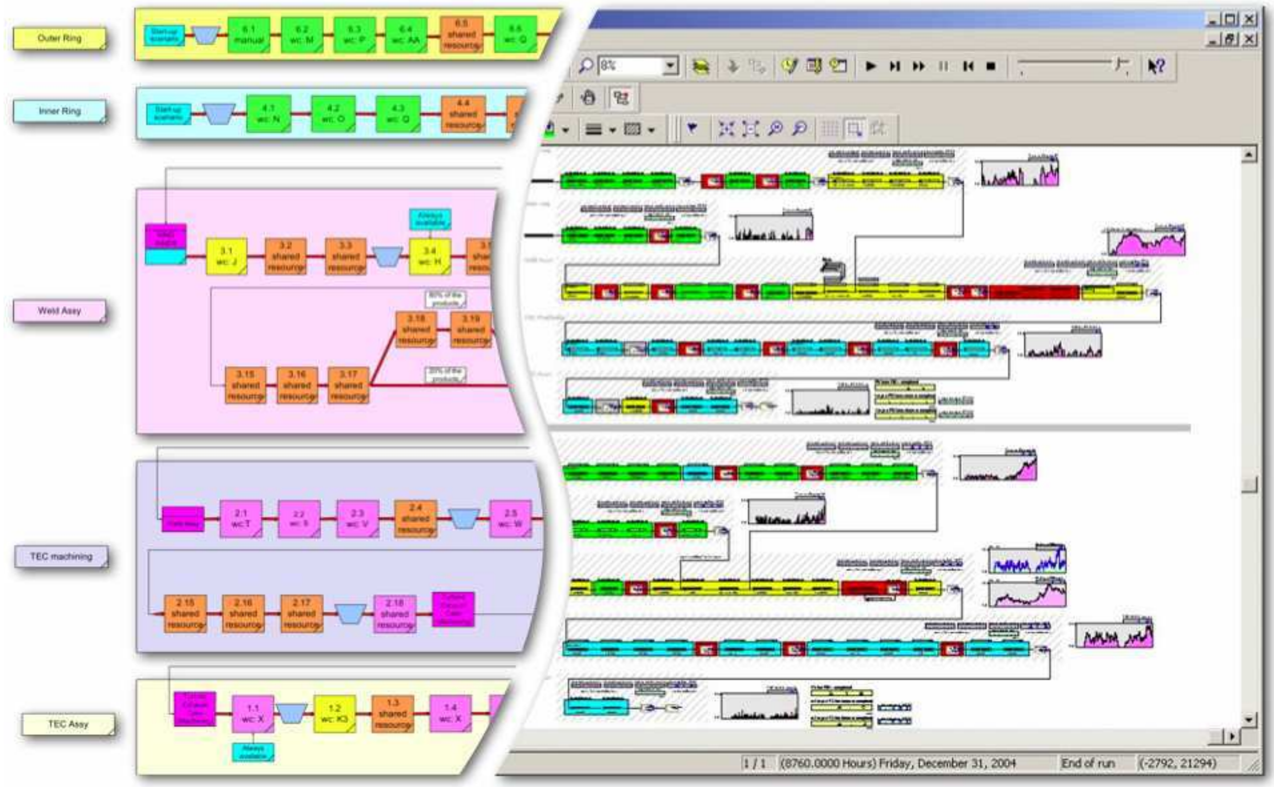

Figure 1: Operations Flow Diagram, and the resulting simulation

Although the modelling task was substantial, most of the activities that were represented fell into just a few categories, such as machining, transportation and joining (assembly or welding) operations. In each case, the activity could be represented via a 'submodel'. These are self-contained collections of Arena entities which, once developed and tested, could be used repeatedly, given unique names and appropriate parameters including the resources required and the processing time. Thus, although the eventual model consists of almost 1500 interlinked elements, most are within proven submodels.

The earliest modelling activity focused upon achieving an 'as-is' representation of the focused factory; this was an MRP-driven system, using due dates and a standard lead time to determine when materials should be launched into the facility. Originally, the launch dates for each component were held within an array, although it was found that the functions of the MRP system were more easily represented within a spreadsheet. The quantity of parts to be launched on each day was read into the model automatically, each time it ran. This had the advantage that a user no longer needed to be an Arena expert in order to create experimental scenarios, increasing the usefulness of the model. A further refinement provided a means for defining the work-in-progress (WIP) at each workcentre at the start of a model run. The focused factory did not start out empty when data collection began; production of both TECs was already well underway. Simulations *can* generally be started empty, and if left to run long enough are likely to reach a steady state (if the system *has* a steady state). However, by taking advantage of the historical data provided by Volvo Aero, the model was populated with workpieces at various stages of completeness at 'time zero'. As a result, it was found that the model would reach a steady state much more quickly, this being observed at around seventy days where an empty model only achieved a steady state after almost two hundred days. When performing a large number of experiments with a complex model, this led to considerable time savings.

MODEL VALIDATION

Validation is an essential pre-requisite to the use of any simulation in experimentation to understand and improve the performance of the system [4]. The 'MRP-driven' model provided a useful means of validation, since the performance of the simulation could be compared with the production history of the real system. This process also served to fine-tune the model and tackle some issues of accuracy. Naturally, some differences were observed; at first the simulation was found to perform far worse than the real system. At peak demand, lead times would increase steadily, as would the amount of WIP in the system as it became choked with material. Investigation eventually revealed that some of the information that had been supplied, describing the operating practices for key machine tools, was out of date since a means had been found to increase their effective capacity. When the model was changed to reflect the new performance data, the results resembled those of the real system. A number of performance metrics were used, including lead time, fill rate, level of WIP and the utilisation of selected machines. All could be compared with historical data, and with results from static simulation, deriving capacity mathematically, given typical processing times. This technique, plus experience within the facility suggested a maximum throughput of twelve TECs per week, and this was borne out via experimentation.

EXPERIMENTATION

All the performance metrics used for validation could also be used as outputs from the programme of experiments, being further augmented by tied-up capital, resilience (rapidity in recovering from a disruption) and robustness (ability to absorb a disruption). It will be appreciated that pursuit of some target metrics will only occur at the expense of others; a holistic appreciation of these tradeoffs is required, for example balancing the cost of WIP against the value of its presence in smoothing the flow of operations. To reiterate the aims of this work, it was desired to investigate the opportunities for improving throughput and/or delivery performance, without requiring additional investment. The experiments were centred upon alterations to the logistic control of the facility, while measuring its performance in a turbulent environment where demand patterns could change, where the delivery of raw materials was sometimes unreliable, and where operations were occasionally complicated by machine breakdowns or quality problems that required rework. Each of these deviations from the normal state of the manufacturing system was representative of the kind of problems that had been observed, historically, and each could be switched on or off, to see how the simulated system coped in each case.

Several different logistic control strategies were evaluated against these deviation scenarios. As would be expected, some strategies tend to produce better results against certain metrics, under certain circumstances. Good results (short lead times, low tied-up capital, etc.) might be observed in a system that is more highly susceptible to deviations such as changing demand patterns.

ACHIEVING LOGISTIC CONTROL WITHIN THE SIMULATION

It should be possible to simulate any logistic control system within a suitably-designed model, and it was a goal of this work to examine several such systems. By extending the separate, spreadsheet-based tool that has been used to specify the schedules for demand and supply, a means was developed whereby the logistic control strategy could also be described parametrically, allowing a range of experiments to be conducted more readily and efficiently. The as-is representation of the current control method had reproduced the functions of an MRP system; the only parameter that could be controlled to influence the performance of this system was the standard lead time; the offset between when a product is due and when work should commence (or when an order should be dispatched upstream). This calculation was performed within the spreadsheet; effectively the MRP-driven model simulates a planning, not control system, and when a disruption occurs the system does not react well. When a bottleneck develops, the component launch schedule is not changed, and the result is lead times and WIP levels that tend towards infinity. Small test models created in Arena had shown how other systems of logistic control could be represented, the following being created:

- A drumbeat system, using signalling to release parts from 'hold' modules at regular intervals, so as to avoid discrepancies brought about by different processing times
- A Kanban system [5] modelling the flow of tokens that had to be present at a workcentre before an operation would commence
- A Kanban squares system, where an operation was triggered when a space developed in a buffer immediately downstream
- A drum-buffer-rope system [6, 7] with elements of both 'push' and 'pull' logistic control, centred upon the most constrained resource

The situation in the focused factory meant a 'textbook' implementation of some systems of logistic control was impractical. Given the low volume of parts processed, workflow tended to be 'lumpy' (not well suited to Kanban) and the high value of each component meant that it was not economic to hold parts in a buffer located after every machine. The mixture of product types with different processing times, and some dependence upon resources outside the boundaries of the focused factory, complicated the notion of communicating a 'drumbeat' to all operations. Finally, the drum-buffer-rope approach was made more difficult because the bottleneck constraint tended to move, depending upon the product mix then being pursued. (This also posed problems for a Kanban system, since it was difficult to select the best number of tokens to circulate.)

While some exemplar facilities do exist, it must be recognised that many businesses actually operate a partial or hybrid implementation of a system of logistic control, where some areas of their facility are leaner than others. Economic order quantities and economic batch sizes at certain machines may well influence the evolution of the system. To the lean manufacturing purist, any such issues offer themselves as a target for process redesign; in the aerospace value chain, however, volumes will always be very low, compared to a large automotive or electronics plant. It was thus necessary to have a means of simulating not only the 'classic' logistic control concepts, but also a variety of hybrids.

One such hybrid was achieved by combining some of the features of the MRP-driven simulation with the triggering method for the 'Kanban squares' system. Instead of placing Kanban squares (buffers) after every machine, since we could not justify the cost of populating those squares with WIP, they were located at the end of a *sequence* of operations. The breakpoints were chosen to match those used at Volvo Aero, on whiteboards that showed the status of the facility. These sequences resembled Period Batch Control [8, 9] in that a group of processes of different duration were combined into groups with similar overall duration. With the groupings used, a workpiece could be expected to advance from one sequence to the next, each week – and therefore we expected each sequence to exhibit a WIP level that was approximately equal to a week's output for each TEC type. (There was one exception; one of the sequences contained several lengthy operations, and was of double duration. This is a permissible feature of Period Batch Control.)

The Kanban squares located at the end of each sequence were not merely a buffer, but also the instrument of logistic control. They only released components into the sequence downstream if the level of WIP within that sequence (including its own buffer) had fallen below a target figure. This target figure determined the leanness of that sequence of operations, being in effect the number of kanbans being circulated within that area of the factory. In reality, there was no need to model the movement of tokens within the simulation; keeping track of the number of workpieces within a sequence and comparing this with the target figure achieved the same result.

The target figure for WIP was specified within the same spreadsheet that detailed the delivery schedule, standard lead times, raw material availability, etc. Thus, we had produced a factory simulation system that could be configured by anybody who could use a spreadsheet, rather than one that required the involvement of an analyst. In such a system it became very simple to change between representing a 'push' or 'pull' system of logistic control. For example, if we specify a target figure for WIP that is very high (say, 9999) then the preceding buffer will *always* allow parts through. In effect, that sequence becomes a 'push' system. Conversely, by specifying a low target WIP figure, we impose limits and can then explore their consequences in terms of lead times, fill rates and tied-up capital, etc. Under a conventional approach to factory simulation, each system of logistic control to be explored would have required that a variant of the factory model be developed, requiring time and effort, and perhaps introducing errors since each change to the model leads away from the validated system.

RESULTS OBTAINED

Since the focused factory operated in a value chain that was subject to a high level of variability, the experiments to which it was subjected involved deviation scenarios. Rather than attempting to optimise the performance of the factory under 'best case' conditions, we aimed to see how it performed when faced with problems such as fluctuating demand, late arrival of raw materials, quality problems and occasional machine breakdowns. For example, Figures 2 and 3 show a comparison between a pure 'push' system and a pure

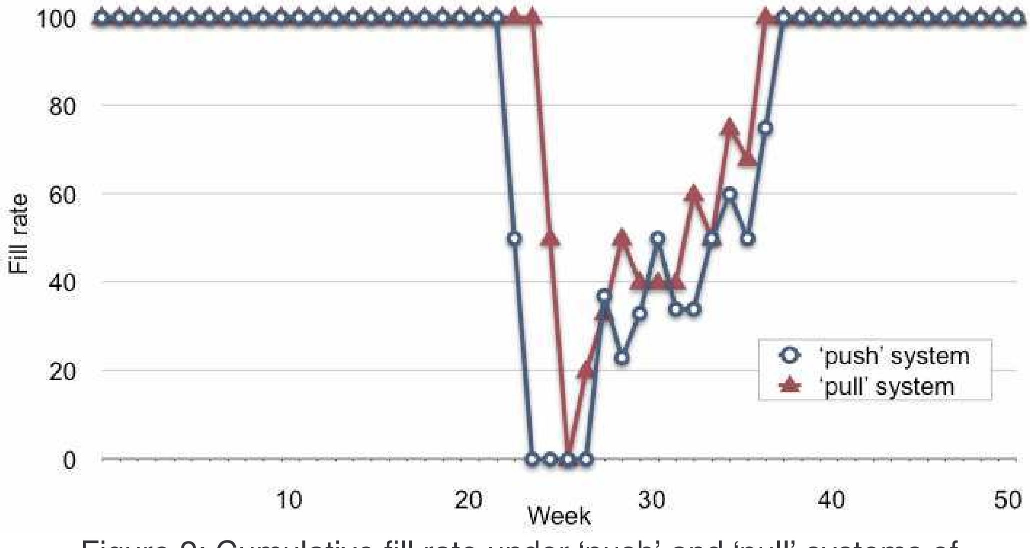

Figure 2: Cumulative fill rate under 'push' and 'pull' systems of logistic control, when suffering an identical component shortage

'pull' one, in the event of a temporary interruption in the supply of a key component for one TEC. Both systems suffered the same shortage, but the 'pull' scheduled system responded better in terms of maintaining the fill rate for longer, and then returning to the delivery schedule more quickly. It is therefore both more robust and more resilient. It also exhibited reduced tied-up capital, since the 'push' system continues to launch the other raw materials into the system, despite the fact that the work cannot be completed. Under a steady state, where there are no disruptions to the focused factory, the 'push' system outperforms the 'pull' one, but by holding components within sequences or buffers, the 'pull' version demonstrates real value in an uncertain environment.

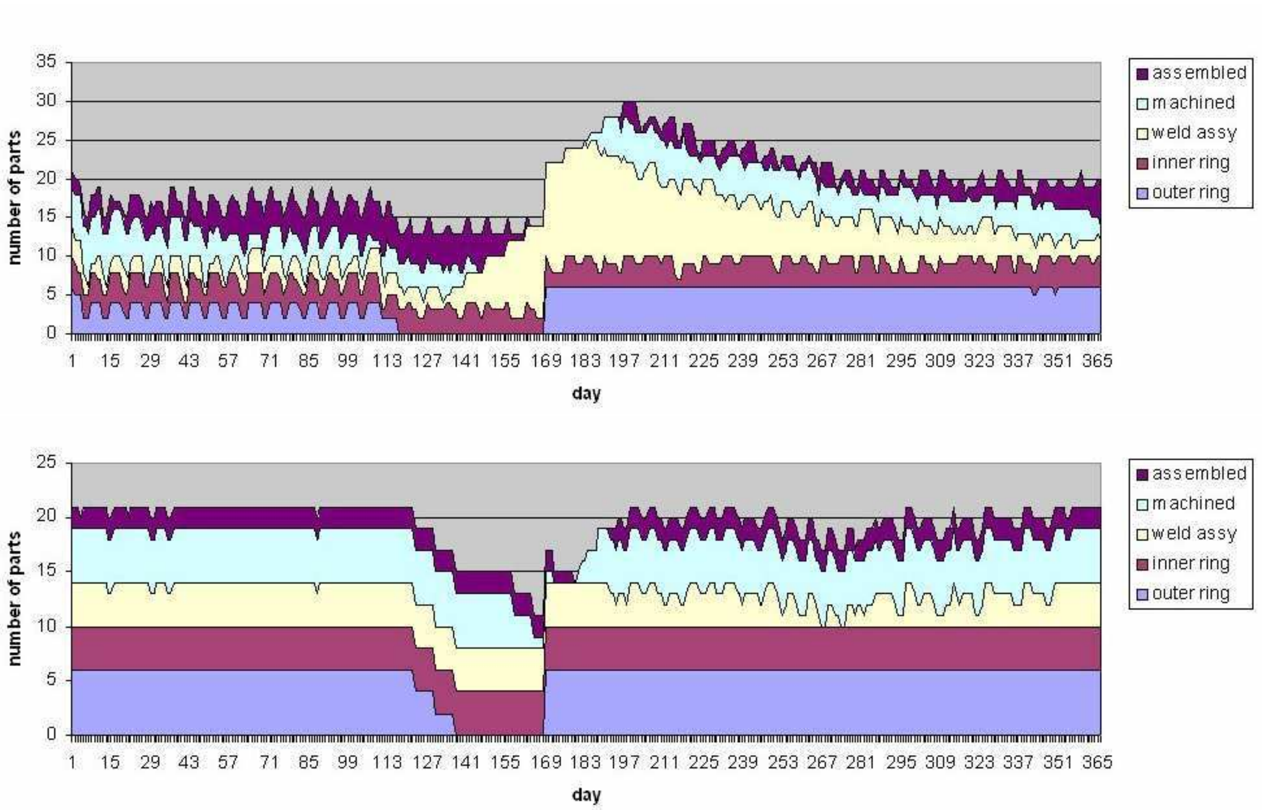

Figure 3: WIP levels observed under 'push' and 'pull' logistic control, when suffering from an identical component shortage

Further tradeoffs between leanness and robustness can be explored by altering the target figure for WIP in each sequence, for either TEC type. Our experimentation suggested that in circumstances such as these a certain level of WIP can have value in that it allows fill rates to be maintained, and speeds recovery. If it is known that disruptions such as the component shortage used here are typical and likely to occur then it might well be worthwhile implementing the new logistic control scheme, with the simulation results used to support a cost-benefit analysis. While we do not know exactly how much money a major disruption costs the business, there are further, less readily quantifiable costs in remedial actions (overtime, managerial input, making special deliveries, etc.) and perhaps penalty clauses when plans break down. A simulation like the one described in this paper allows planners to make informed decisions about contingencies and the level of risk they are prepared to tolerate.

CONCLUSIONS

This paper has described a novel, parametric system which allows different logistic control approaches to be applied to a validated simulation model. This allows a large range of experiments to be conducted, representing different types of control strategy, with various parameters, without altering the simulation model itself. It also allows the creation of hybrid systems of logistic control with multiple 'pull' and 'push' scheduled segments in the operations flow, if desired. This system has facilitated experimentation to investigate the impact of a number of different sources of variability, making use of a broad range of performance metrics. Using the example of a supply shortage, this paper described how a system of logistic control that might not appear to be optimal under ideal conditions can come into its own, in the event of a disruption.

When changes to product designs or the production facility are required, the parametric model also simplifies the process of updating the simulation, since the need for multiple models representing various logistic control scenarios has been eliminated. This reduces the cost and time required, and should increase the users' degree of confidence in the consistency of any alterations made.

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