COMPARING MATERIAL FLOW CONTROL MECHANISMS USING SIMULATION OPTIMIZATION

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ABSTRACT

In this study, discrete event simulation is used for comparing the performance of three material flow control mechanisms: push-MRP, Generic Kanban System (GKS) and generic Paired-cell Overlapping Loops of Cards with Authorization (GPOLCA). The former does not impose restriction to the number of jobs that are released into the supply chain. The latter two are card-based control mechanisms, where the number of jobs in the supply chain is restricted. The simulation models of these mechanisms are developed in Arena® and optimized using OptQuest®. The average total work in process and the average system throughput are used to evaluate the performance of the mechanisms. We found that GKS outperforms GPOLCA and MRP for high levels of throughput.

Keywords: simulation optimization, GPOLCA, GKS, MRP, ARENA, OptQuest

1. INTRODUCTION

Global competition has forced manufacturers to seek innovative ways to manufacture and control the flow of materials. The success of just-in-time (JIT) production, along with their pull production and logistic control methods, has led to considerable interest in the study of control mechanisms for manufacturing systems (Krishnamurthy and Suri 2009). These mechanisms can be classified into push, pull or hybrid push-pull (Hopp and Spearman 2004).

Push systems are typically associated with material requirements planning (MRP). Pull systems are also called kanban control systems (Krishnamurthy and Suri 2009). The Toyota Kanban System (TKS) (Sugimori 1977) is a card-based pull system that has attracted the attention of many companies. However, it was created to fulfil the specific needs of a company (Toyota). It is not suitable in situations with unstable demand, processing time instability, non-standardised operations, long setup times, great variety of items, and raw material supply uncertainty (Junior and Filho 2010). Thus, variations (or adaptations) were created to adapt TKS to the companies' specific reality. For example the Generic Kanban System (GKS) was proposed by Chang and Yih (1994) as an adaptation of TKS for non-repetitive production environments. Junior and Filho (2010) review the literature regarding variations of TKS.

Given the numerous control mechanisms introduced in recent years, it is not an easy task to evaluate which is the best approach for a specific situation. Thus it is an important issue to address the problem of how to compare these mechanisms.

In this study we use simulation optimization to: first, optimize and then, compare material flow control mechanisms. The simulation models were developed in Arena® (Kelton and Sadowsky 1998, Dias, Pereira, Vik and Oliveira 2011) and the control mechanisms were optimized using the OptQuest® tool (Bapat and Sturrock 2003, Rogers 2002).

A case study was developed to demonstrate the methodology by evaluating the performance of a recently introduced mechanism called generic Paired-cell Overlapping Loops of Cards with Authorization (GPOLCA) (Fernandes and Carmo-Silva 2006) along with existing control mechanisms, such as GKS and push-MRP (which is used as a benchmark mechanism) in the context of a small supply chain with multi-products and stochastic operation times.

This paper has two purposes: one is to demonstrate how simulation optimization can be used to solve complex design and control problems; the other is to evaluate the performance of three material flow control mechanisms, namely GKS, GPOLCA and push- MRP.

The paper is organised as follows. In the following section, section 2, a description of the studied material flow control mechanisms is provided. In section 3 the case study and the research design and experimental setup are described. Results and findings from the experiments are provided in section 4. Finally section 5 summarizes the study conclusions and includes directions for future research.

2. MATERIAL FLOW CONTROL MECHANISMS

Each material flow control mechanism coordinates the release of jobs to the supply chain and its progress from one stage to another in different ways. Thus, this section describes how GKS, GPOLCA and push-MRP operate as illustrated in Figure 1.

The GKS mechanism, introduced by Chang and Yih (1994), is a material flow control mechanism suited to make-to-order MTO non-repetitive and dynamic production environments. One characteristic inherited from the TKS is that it uses a well-defined number of cards for each stage of the supply chain, as a means of controlling the work-in-process (WIP). These cards (or kanbans) are not specific of any particular product, contrarily to what happens in the TKS, and thus can be attributed to any job waiting to be released into the system. A job cannot be released unless it acquires all the cards that it needs, from each supply chain stage, according processing requirements, as long as there are cards available, i.e., not yet allocated to jobs. The number of cards allocated to a job, for each processing stage in the supply chain, depends on its workload, since each card represents a specific amount of workload. After release jobs are pushed through the supply chain and, as they are completed at each stage, the attached cards are dropped to the respective cards' boxes, becoming available for new requests, i.e. for allocation to new jobs waiting to be released. Figure 1a) illustrates the operation and the elements of the GKS material flow control mechanism.

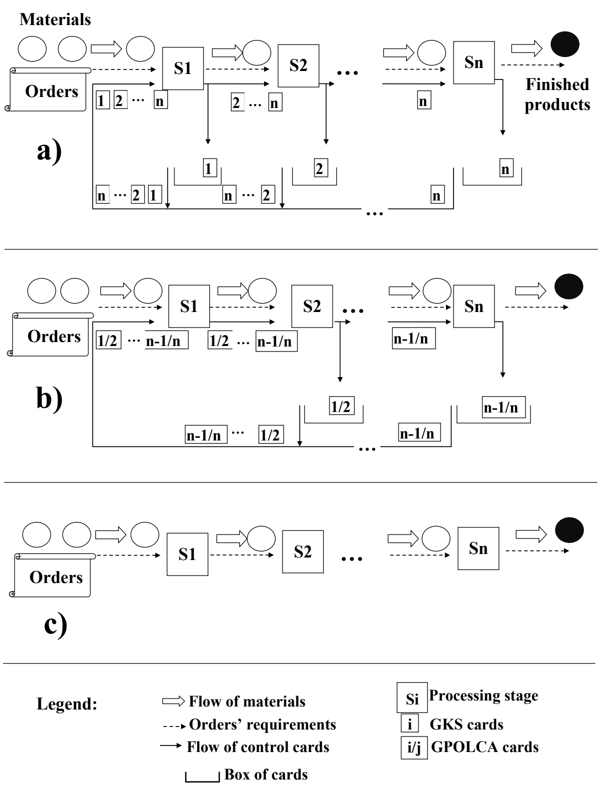

Figure 1: Material flow control mechanisms: a) GKS, b) GPOLCA, c) Push-MRP.

GPOLCA was introduced by Fernandes and Carmo-Silva (2006). Figure 1b) illustrates the GPOLCA mechanism. It is also suited for MTO environments. GPOLCA adapts the POLCA (Suri 1998) mechanism to production environments with high routing diversity, by controlling job release through a combination of planned release dates and production authorization cards, which are allocated to pairs of stages in a supply chain. Moreover, the second stage of a pair in a card is the first in the card that must follow, according to job routing. A clear operating advantage of GPOLCA in relation to GKS, resulting from this, is that the cards have routing information, i.e. it is always possible to know, solely based on the GPOLCA cards to which stage to send a job after it has been processed in another. Nevertheless GPOLCA mechanism controls the release and the flow of work in a manner similar to GKS. Thus, GPOLCA also uses generic cards, i.e. cards that are not specific of any particular product, to control the number of jobs or the workload in the supply chain, and a job to be released must seize the required number of cards. However, cards only become available after the processing is carried out on the second stage of the pair of stages of the card.

In the push-MRP mechanism job release is not controlled by production authorization cards, which means that no limit is imposed to the number of jobs in the shop floor neither to the flow of work between the supply chain stages. Job release is based only in planned release dates and jobs start processing at stages according the dispatching mechanism adopted. Figure 1c) illustrates the operation and the elements of the push-MRP mechanism.

3. SIMULATION MODEL AND EXPERIMENTAL DESIGN

3.1. Simulation model

A discrete-event simulation model was developed using Arena® software. We consider a supply chain with two products types and three stages, identical to that used by Krishnamurthy et al. (2004) (see Figure 1 and Figure 2). A stage represents a major processing function in the supply chain, e.g., procurement of a raw material, the fabrication of a part or the subassembly of a component, test of a finished product and the transportation of goods from a central distribution centre to a regional warehouse.

The physical and operational configuration of the production system includes:

- The same routing for all jobs (products): first they are processed at stage 1, then at stage 2 and last in stage 3;
- A Poisson process for the demand arrival rate;
- Exponentially distributed job processing times at each stage with mean equal to one time unit;
- Set-up times considered as part of the operation times;
- First-come-first-served (FCFS) priority dispatching at all stages of the supply chain.

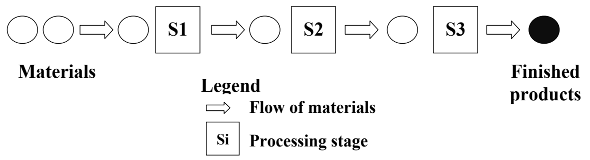

Figure 2: Simulated three-stage supply chain

We also consider the presence of short-term product mix imbalances caused by changes in demand. These changes take place over a short period of time, i.e. during a day, at the seventh day of every week.

The two types of jobs have an equal probability of arriving to the system, except at the seventh day. In this day the total demand for the two products, λ1+λ2, is kept unchanged, acting upon the demand rate ratio λ1/λ2 to achieve a product mix change. This ratio was set to 1/2. To ensure that workload stays balanced, the average service time μ of each job in each supply chain stage is kept unchanged and, therefore equal to one. Thus, the following equation applies:

$$\frac{\lambda_1\mu_1+\lambda_2\mu_2}{\lambda_1+\lambda_2} = 1 \qquad (1)$$

Assuming a service time ratio μ1/μ2 of 2 the expected mean service time of each job is determined by equation (1).

3.2. Experimental Design

The experimental factors and simulated levels considered in this study are summarized in Table 1. The material flow control mechanism is tested at three levels (MRP, GPOLCA and GKS), job arrival rate is tested at 12 levels, varying arrival from 0.5 to 0.95 jobs per time unit. This results in a full factorial design with thirty-six, i.e. 3x12, test cases.

Table 1: Experimental factors and corresponding levels

Factors	Levels		
Mechanism	MRP	GPOLCA	GKS
Release rate	0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.875, 0.9, 0.925, 0.95		

The main objective of applying a material flow control mechanisms in supply chains is reducing work in progress (WIP). To achieve this objective, we optimize the number of GKS and GPOLCA cards using OptQuest. Thus the release rate at these mechanisms results from the minimum number of cards that leads to the desired system throughput (TP).

For all material flow control mechanisms the performance measures monitored are TP, WIP and Flow time. TP is measured as the mean number of completed jobs per time unit. WIP is defined as the number of jobs released into the production system, but not yet finished. Flow time is measured as the time between the job release and its completion.

During simulation experiments, data is collected under steady state. Each simulation was run for 50 independent replications of 96000 time units with a warm-up period of 9600 time units to ensure that steady-state condition was reached.

3.3. Simulation optimization for card-based systems

To compare material flow control mechanisms first they must be optimized. Since material flow control mechanisms, such as GKS and GPOLCA, enforce WIP limits by restricting the number of cards that can be in the system, and consequently the buffer capacity at stages, this number is a critical parameter that must be optimized.

For determining the minimum number of cards needed for each throughput rate, we used the tool OptQuest for Arena.

Although the maximum throughput can be achieved with any number of cards above the minimum, the objective is to minimize the number of cards that achieves the desired throughput. This, in turn, reduces the WIP for each card-based material flow control mechanism.

The minimum number of cards, obtained from the best solution given by OptQuest, is then used to run the simulation in order to evaluate and compare the material flow control mechanisms.

We exemplify the optimization procedure adopted focusing on GPOLCA. In this case, Num_Card_1_2 and Num_Card_2_3 are variables in the Arena model, identified as user specified Controls in OptQuest. For these controls we specified the range to be used by the optimizer, through low and high boundaries.

In the Responses option we have to select items that we want to use in the constraint, in this case the Arena variable TRP (throughput).

A constraint was defined in order to ensure a TRP larger than 99.98% of the release rate, as shown in Figure 3. For instance, for the average release rate of 0.50 jobs per time unit in the Arena model, we use in OptQuest the Constraint: *[TRP] > (4999/10000).*

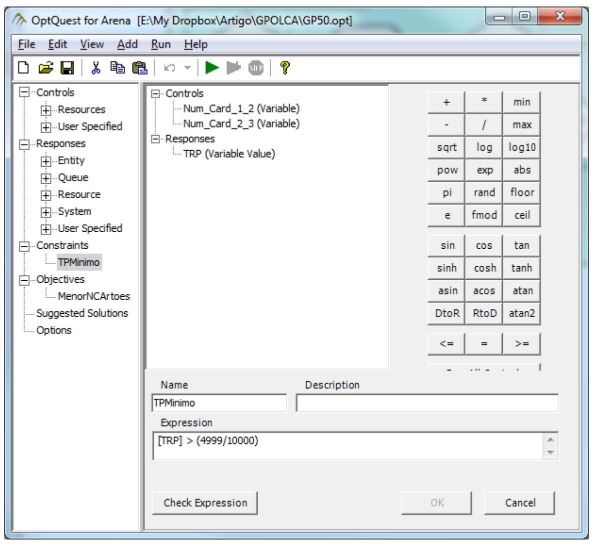

Figure 3: OptQuest constraint

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The Objective function is: *minimize [Num_Card_1_2] + [Num_Card_2_3]*. The cards number boundaries and the constraint value varies according to each release rate. This was evaluated for all the release rate values tested.

The OptQuest optimization run, with the above parameterization, is shown in Figure 4. In the graphic of this figure, we can follow the best objective function value evolution. For each iteration OptQuest performed a simulation using different values for the number of cards, keeping the best solution founded until it runs all the possible combinations. The OptQuest best feasible solution, i.e. number of cards that ensures minimum WIP for meeting the required TRP is also shown in Figure 4. For the case where TRP is 0.5 and GPOLCA is used, the best solution funded by OptQuest was 2 and 3 cards respectively for the card type 1_2 (pair 1 and 2 of processing stages) and type 2_3.

The amount of time needed to complete each optimization can be between ten minutes to one hour, depending on the high boundary value defined to the cards number, in a core 2 Duo 3.16GHz processor.

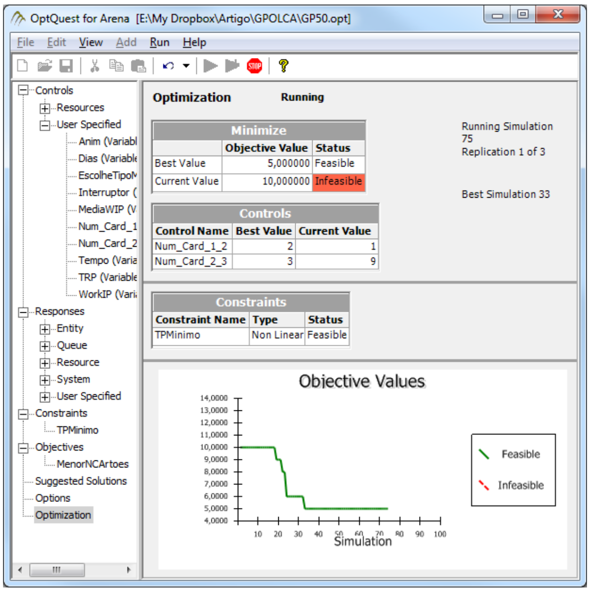

Figure 4 : OptQuest running

4. RESULTS OF THE EXPERIMENTS

In this section we report the results of the set of experiments conducted in order to compare the material flow control mechanism performance. The 95% confidence intervals were developed for the mean value of each performance measure, namely WIP, Throughput (TP) and Flow Time.

Results are shown in Figure 5 and Table 2. The former shows a production logistic curve for each of the control mechanisms studied: push-MRP, GPOLCA and GKS. These curves show the average WIP as a function of the system throughput. A point on a curve corresponds to the best cards configuration of the mechanism that achieves that throughput with the lowest WIP. A particular control mechanism is superior to another if, for a given TP it shows a lower WIP.

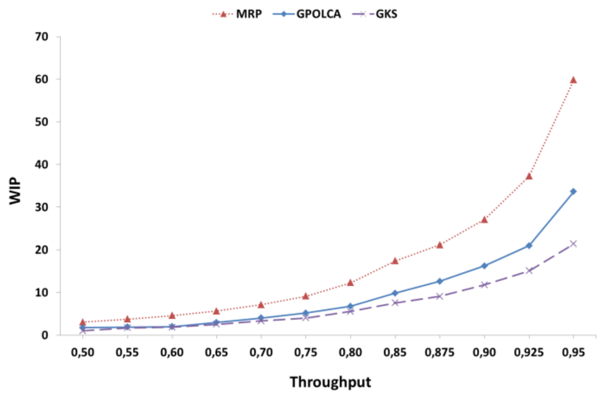

Figure 5: Mechanisms performance

Table 2: Mechanisms' performance for a TP of 0.95

Mechanism	WIP	Flow time
MRP	59.8 ± 2.19	62.6 ± 2.07
GPOLCA	33.6 ± 0.23	36.4 ± 0.14
GKS	21.4 ± 0.15	23.3 ± 0.11

It is known that as throughput approaches the system capacity, i.e. the maximum possible throughput, WIP tends to infinite. This can be observed in Figure 5.

Table 2 shows performance results for a throughput of 0.95. A paired t-test revealed that, the difference between mechanisms, for WIP and flow time, is significant at 95% confidence level.

Analysing the above results the following observations can be made. The total WIP required to meet a particular TP is higher under MRP, particularly for high levels of TP. Results under GPOLCA are clearly better than under MRP and improve as the system TP increases. For a TP of 0.95, changing from MRP to GPOLCA produced a reduction in WIP of 44%. This means that the same TP can be obtained under GPOLCA with less WIP, as shown in Table 2, and also lower flow time, as could be expected by the Little's law. The better performing mechanism is GKS having a reduction of WIP in relation to MRP in about 64% for a TP of 0.95. Over a large range of TP values, GKS and GPOLCA have practically identical performance rates. However, at the highest levels of TP, GKS performs better than GPOLCA. In fact, for the stated TP objective of 0.95, changing from GPOLCA to GKS reduces WIP in about 36%.

From these results we may conclude that the strategy adopted by GKS of controlling the release of jobs to every stage of a serial supply chain performs better than the strategy used by GPOLCA of controlling the release of jobs to pairs of stages.

5. CONCLUSIONS

This paper considers the material flow control within a supply chain with stochastic operations times and highly variable product demand. Three material flow control mechanisms were compared by simulation, namely: push-MRP, GPOLCA and GKS, all suitable for MTO environments. Before being compared, the latter two were first optimized in relation to the number of production authorization cards (or kanbans). These card-based mechanisms showed to successfully reduce work-in-process, with GKS performing better than GPOLCA.

In the study the FCFS dispatching rule was used. An important avenue for future research would be to investigate how the dispatching rule interacts with the materials flow control mechanisms. It would also be interesting to investigate which method yield robust performance in the presence of bottlenecks.

Since several other material flow control mechanisms have emerged recently it is important to identify the suitability of them to the demand environment studied and confront them with GKS. This will help to improve knowledge about the mechanisms that should be recommended for supply chains of high variable product demand.

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REFERENCES

Bapat, Vivek and David T. Sturrock. 2003. The arena product family: enterprise modeling solutions. In *Proceedings of the 35th conference on Winter simulation: driving innovation* (WSC '03), New Orleans, Louisiana, USA, December 7-10, 2003, 210-217,

Chang, T.M., Yih, Y., 1994. Generic kanban systems for dynamic environments, *International Journal of Production Research*, 32 (4), 889-902.

Dias, L.S., Pereira, G.B., Vik, P., Oliveira, J., 2011. Discrete Simulation Tools Ranking – a Commercial Software Packages comparison based on popularity, *ISC 2011 - Industrial Simulation Conference*, 5-11, June 6-8 2011, Centro Culturale Don Orione, Venice, Italy.

Fernandes, N.O., Carmo-Silva, S., 2006. Generic POLCA—A production and materials flow control mechanism for quick response manufacturing, *International Journal of Production Economics,* 104, 257-262.

Hopp, W.J., Spearman, M.L., 2004. To Pull or Not to Pull: What Is the Question?, *Manufacturing & Service Operations Management*, 6, 133-148.

Junior, L.M., and Filho, G.M., 2010. Variations of the Kanban system: Literature review and classification. International Journal of Production Economics, 125(1), 13-21.

Kelton, W.D., Sadowsky, R.P., Sadowsky, D.A., 1998. Simulation with Arena, Boston-USA, McGraw-Hill.

Krishnamurthy, A. and Suri, R. 2009. Planning and Implementing POLCA: A Card-Based Control System for High Variety or Custom Engineered Products, *Production Planning and Control*, 20 (7), 596-610.

Krishnamurthy, A., Suri, R., Vernon, M., 2004. Re-examining the performance of MRP and Kanban material control strategies for multi-product flexible manufacturing systems, *International Journal of Flexible Manufacturing Systems* 16, 123-150.

Rogers, P. 2002. Simulation of manufacturing operations: optimum-seeking simulation in the design and control of manufacturing systems: experience with optquest for arena. In *Proceedings of the 34th conference on Winter simulation: exploring new frontiers* (WSC '02), San Diego, California, USA, December 8-11, 2002, 1142-1150,

Sugimori, Y. Kusunoki, K., Cho, F. and. Uchikawa, S., 1977. Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system *International Journal of Production Research, 5 (6), 553-564.*

Suri, R., 1998. *Quick Response Manufacturing: A Company-Wide Approach to Lead Time Reduction*. Portland-USA, Productivity Press.

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