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A SIMULATION APPROACH FOR PERFORMANCE EVALUATION OF PULL, PUSH SYSTEMS

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ABSTRACT

This paper studies the effects of uncertainties in operational factors on performance of a manufacturing system. A simulation model of a hypothetical manufacturing system with multi-stage subassembly is developed and used to study such effects. The study uses simulation as long run planning tools for improving manufacturing performance and compares MRP-push systems versus Kanban-pull systems. A simulation language for discrete-event simulation, SIGMA, is used to model for pull, push systems. An iterative heuristic algorithm is employed to determine initial model parameters: the number of Kanban for pull systems, and safety stock levels for push systems. Simulation experiments are conducted in an environment involving changes in two operational factors: demand and processing time. The experimental results indicate that the pull system outperforms the push system in terms of lead time and work in process (WIP) inventory in such environment.

1 INTRODUCTION

Manufacturing industry has faced increasing competition in the global market where competitive strategy requires the company to maintain high productivity and flexibility to adapt to market requirements. To compete in highly competitive market, a company is required to realize an effective production system.

In fact, each production system can perform well in certain environments. As the fluctuation of demand increases, the safety stocks necessary to minimize the probability of stock out also increased. The processing time variability increases the uncertainty of lead-time and could lead to more fluctuation of inventory. In such circumstance, each production system becomes effective in meeting product demands and keeping lowest possible inventory. The study investigates the effects of operational factors involving fluctuation in demand and variance of processing time on performance measures.

In recent years, many researchers have developed simulation models for investigating operational factors on performance of pull, push systems.

Rees, Huang, and Taylor (1989) described a simulation model for a hypothetical production operation with multiple workcenters, machines and product structures, and serial and assembly operations. Their study investigated relationships between the number of machines and different items processed in term of cost-effectiveness. Based on experimental results, they concluded that the Kanban system was implemented with shorter setup and cycle times than MRP system.

The study by Sarker and Fitzsimmons (1989) investigated the effects of processing time variability on the performance of push and pull systems. Experiment results revealed that the output rate of a pull system is more sensitive to high variability of processing time than that of the push system. Additionally, the observation has been made that a pull system is always better at minimal WIP than the push system.

Beamon and Bermudo (2000) developed a hybrid push/pull production control algorithm and tested for use in a multi-stage assembly-type repetitive manufacturing environment. The algorithm is primarily based on a JIT approach, but uses dependent demand aspects of manufacturing resource planning (MRP II) to manage the intermediate inventories. Their simulation results showed the algorithm to be effective in minimizing WIP while sustaining output capacity, with relatively little sacrifice in total lead time from the best observed values. The experimental results indicated that the hybrid system at 95% confidence level outperforms the pure pull system in term of lead-time and outperforms the pure push system in term of WIP.

Many other simulation studies revealed that system parameters also affect on measures of performance. Researchers employed Kanban discipline, and developed iterative algorithms to determine system parameters for their models.

Yan (1995) described a model for determining the number of Kanbans in the environment with general machine breakdown and stochastic demand. In the model, he presented an iterative algorithm for approximating the near optimal number of Kanbans in a system with one machine and one part type. The approach utilized the technique of perturbation analysis that computes an estimate of the gradient of a performance measure with respect to system parameters.

Aytug, Dogan, and Bezmez (1996) gave a method to determine the number of Kanbans by using simulation metamodeling. A cost-based objective function was developed for the purpose of determining the number of Kanbans. The constraints on the number of Kanban set assumed this function use cycle time from given regression equation.

Andijani (1997) developed stochastic simulation model for a multi-stage serial production line. His research investigated the trade-off between the average throughput rate (to be maximized) and the average system time (to be minimized) using Kanban discipline. The results indicated that most of the efficient sets generated by the design rule are identical to those generated by enumerating all combinations of Kanban allocations.

The context of the study develops simulation models for a hypothetical manufacturing system with multiple parts, multiple stages where system parameters of models are determined by iterative method. Evaluating performance for these models that meet product demands conducted in the same experimental conditions.

2 SIMULATION APPROACH AND HEURISTIC METHOD

Performance measures (R) of simulation models can be obtained from simulation runs and the R value depends on the values of input factors ($v_1,v_2,...,v_k$). The model objective is that the expected total output $E[R(v_1,v_2,...,v_k)]$ reaches the desired total output (R_0) over all possible combinations of ($v_1,v_2,...,v_k$).

Stochastic factors used in the models are processing time and rate of order releases, so total output is a stochastic process. Two control variables can be used to adapt to the stochastic process: machine capacity (number of machines) and inventory (initial stock). Since the production system is based on Master Production Scheduling (MPS) and the number of machines is predetermined. As a result, initial stock is used as input factors ($v_1,v_2,...,v_k$) and the values of ($v_1,v_2,...,v_k$) affect to output measures R.

A heuristic method introduced to find out a set of input factors has the following steps:

(1) Estimate the upper bound for each value of input factor ($v_i < u_i$). This upper bound can be estimated in deterministic environment so that total output from combination of all values of u_i achieves the desired total output.

(2) From Bill Of Material (BOM) structure, items (jobs) are classified in levels. Choosing a job as a candidate using a top-down rule, job with higher level will be accomplished before job with lower level. For job i, values of input factors (v_i) is initialized at its upper bound u_i, then the value of v_i is reduced until the smallest values of v_i that average value of R ($E[R(v_1,v_2,...,v_k)]$) still reaches desired total output R_0.

(3) For each decrement of value v_i, experiment with n replications are made to estimate average value of R. The hypothesis test is applied to conduct whether the average of R reaches the desired output value R_0 or not. The smallest value of v_i can be obtained from the result of the hypothesis test. This value is used for other combinations afterward.

(4) Repeat for another job with the same procedure until all jobs have been considered.

The basis of heuristic method in seeking optimum values for input factors is based on the relationship between lead-time (LT), work in process (WIP), and throughput (TH) as the Little's Law formula.

$$LT = \frac{WIP}{TH} \quad or \quad WIP = LT \times TH$$

According to JIT philosophy, the pull system should synchronize demand with production rate. WIP level is in fact the number of Kanbans that is considered as input factors ($v_1,v_2,...,v_k$) for the system. The push system controls part flow based on released orders. Rate of order releases affects quantities of safety stock ($v_1,v_2,...,v_k$) corresponding to WIP level that job spent in the system.

Let ($v_{10},v_{20},...,v_{k0}$) be optimal values of input factors, and desired total output is R_0. For any level of v_i, average total output ($E[R(v_1,v_2,...,v_k)]$) is observed.

As any $v_i < v_{i0}$, observing that $E[R(v_1,v_2,..,v_i,..,v_k)]<R_0$
Any $v_i > v_{i0}$, observing that $E[R(v_{10},v_{20},..,v_i,..,v_{k0})]=R_0$

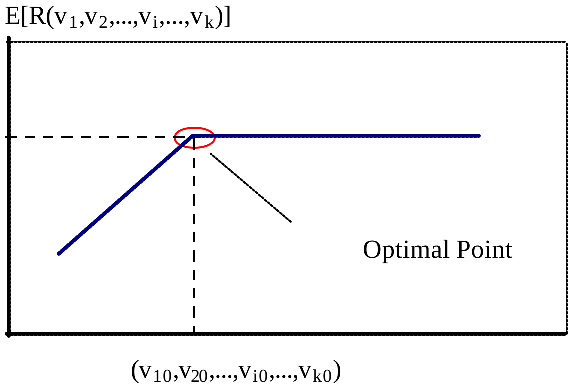


Figure 1: Relationship between value of input factors and expected total output

Consequently, an optimal point can be found that the model reaches the desired total output at the optimal values of input factors. The heuristics may not be optimal, but it provides an algorithmic strategy to reduce system WIP that terminates in finitely many steps.

3 DEVELOPMENT OF SIMULATION MODELS

3.1 The conceptual model

The hypothetical system is a job-shop with three machine groups, six job types. Each machine group consists of some identical machines that produce a particular part with a certain processing time. Jobs have different routings where assembly operations take place at specific machine groups. Further, final product implies job with existing demand while raw material is for job without routing. Figure 2 shows BOM structure and assembly operations under study.

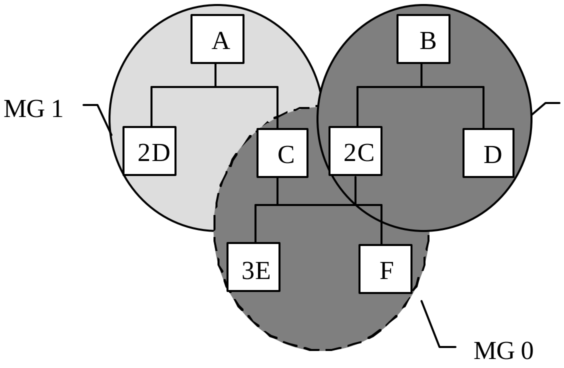


Figure 2: BOM structure and assembly operations

Machine group 0 (MG 0) takes 3 units of job E and 1 unit of job F to produce 1 unit of job C. Machine group 1 (MG 1), where job A is produced, requires joining 2 units of job D and 1 unit of job C together. Machine group 2 (MG 2) is to produce job B that needs 2 units of job C and 1 unit of job D for assembly kit.

The following shortlist presents the detailed assumptions made at the design stage of the model, and the limitations imposed as a result of these assumptions.

(1) The hypothetical system under study suits to repetitive manufacturing environments. Products are standardized, high volumes with little variability in mix of products provided.

(2) Models are designed to produce a mix of products on predetermined routines. Each machine group, a set of identical machines, performs a specific operation.

(3) Processed parts are kept in store, and part movement to buffers depends on control mechanisms. Each buffer is addressed to specific machine group in the assembly line.

(4) Machine capacity is assumed to be unlimited to meet demand of product mix, and the required number of machine is determined from simulation model. Machine breakdowns are not including in the model, and operating time is also assumed to be continuous.

(5) Mean processing time, consisting of loading/unloading time, assembling time, and setup time, is given as input data. Timing and order quantity are scheduled to release based on demand and order lot. Stochastic processes can be updated properly for control variables by making minor changes in parameters and probability distribution.

(6) Container size is assumed to be 1 for all individual parts. In addition, load size of 1 is applied for operation at all workcenters, and jobs are processed under FIFO rule.

A systematical approach is employed to analyze data of the system. Inputs and outputs of the model are shown in Figure 3 below.

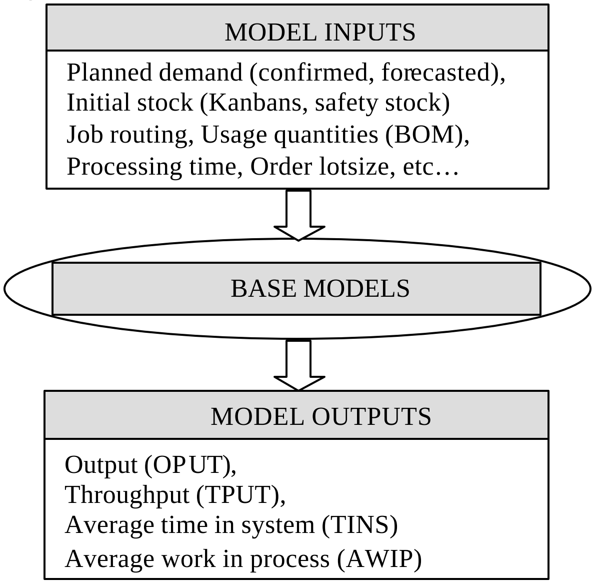


Figure 3: Inputs and outputs of the model

The input data for the model will be read from disk files that allow the model to be updated with the desired changes. Model output provides performance measures of the system. For the purpose of performance evaluation between MRP and JIT models, the following performance measures are estimated in the studied models:

Output (OPUT): The amount of jobs (in units) delivered to customer.

Throughput (TPUT): The average output per unit time (hours).

Time in system (TINS): The average time in system of job.

Average Work In Process (AWIP): The average WIP inventory of job.

3.2 JIT simulation model

Kanban is simply a form of order card that mainly comes in two kinds. A withdrawal Kanban (WK) specifies the kind and quantity of part, which the subsequent process should withdraw from the preceding process, while a Production Kanban (PK) specifies the kind and quantity of part, which the preceding process must produce. These Kanbans are specifically allocated to different parts in the line.

Production at each work center is triggered in response to an actual demand arrival at the end of the lines that associated with final products. Customer demand and order arrival schedules to be released can be based on the MPS. The information about order releases at the end of line is transmitted to the rest of the line via part specific Kanban.

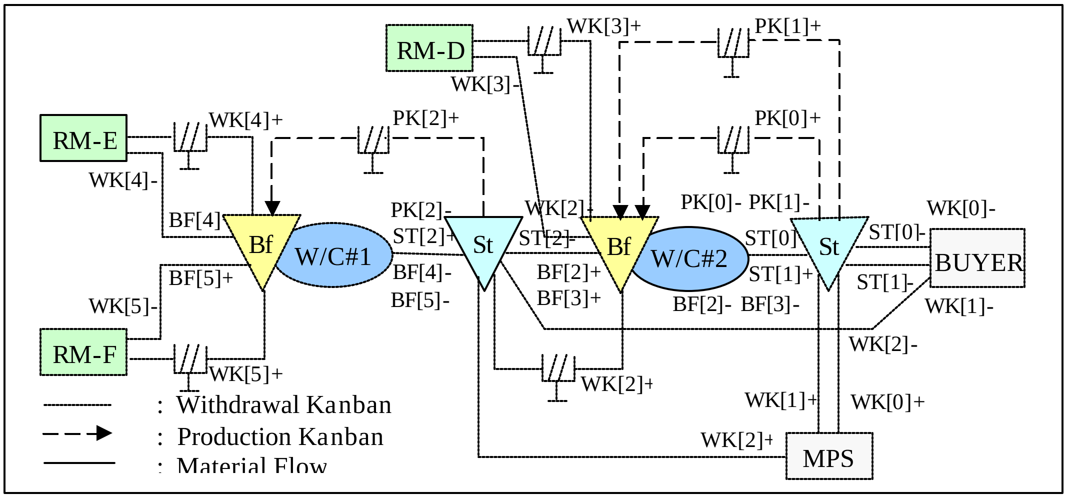


Figure 4: Diagram of JIT-pull control system

The diagram in Figure 4 illustrates the model with the earlier BOM structure with three jobs A, B and C indexed by 0, 1 and 2 respectively. W/C#1 (Workcenter 1) includes machine group 0, while W/C#2 includes machine group 1 and machine group 2. Index of PK and WK simply express job types, a signal of plus or minus states changes of Kanban cards.

When a job order is released, Withdrawal Kanban is increased (WK[]+) according to order lot. If the required order is satisfied with available quantities at store, the order will be delivered to customer right away from available inventory. Then Production Kanban is attached to the removed container and become dispatching information for the process. As a result, Production Kanban is increased (PK[]+) while Withdrawal Kanban is decreased (WK[]-) with the same delivered quantity. The production orders are then authorized to move the required components to the buffer. Workcenter will produce the part to replenish withdrawn quantity when the required components are available in the buffer. When a container has been refilled, a card is put on the container, and moved to store. At that time, Production Kanban is decreased (PK[]-). Production activities of the assembly line are connected in a chain manner to the preceding processes of the entire processes.

The simulation model can be divided into four sections: Data Input, Machine Capacity Planning, Order Releasing, and Pull Control System. The JIT simulation event graphs model is presented as shown in Appendix A.

In the simulation model, the resident entities are machines, stores, and buffers associated with jobs and machine groups. The transient entities are jobs, Kanban flowing through the system. The attention can be focused on Kanban system in order to explore the most distinctive feature of Kanban system. The pull control system includes three basic activity cycles relating to Kanban information and material flows. A rectangular cycle, a triangular cycle, and a compound activity cycle are considered as follows:

The rectangular cycle (STORE, PKPOS, BUFFER, WKPOS and back to STORE) is designed to control the Kanban flows (Production Kanban and Withdrawal Kanban). The process will start when the jobs are released at the STORE vertex where the right quantities and type of Kanban are exchanged. The pull control mechanism schedules its predecessor through PKPOS, BUFFER, and WKPOS vertexes. The cycle stops when the tasks on the job routing are completed.

The first triangular cycle (BUFFER, WKPOS, STORE and back to BUFFER) is designed to control material flow between workcenter. This activity cycle plays the roles for both information and material flow. While the compound activity cycle (JOINQ, and the cycle of BUFFER, START, FINISH, NEXTQ and back to BUFFER) is designed only material flow within particular workcenter, this cycle shows busy or idle status for each machine group. If no machines are idle, then the job joins in queue. Machines continuously assemble components to produce parts until available components in BUFFER are depleted.

The rectangular cycle is viewed as the activity of transient entity that moves between resident entities (from machine to machine) while the triangular cycles are the activities of a resident entity (machine group) processing successive transient entities (Jobs).

3.3 MRP simulation model

In MRP system, the key inputs are a bill of material (BOM), master production scheduling (MPS), and inventory records. Using this information, the MRP system identifies actions that operations take to stay on schedule, such as releasing planned orders, and order quantities.

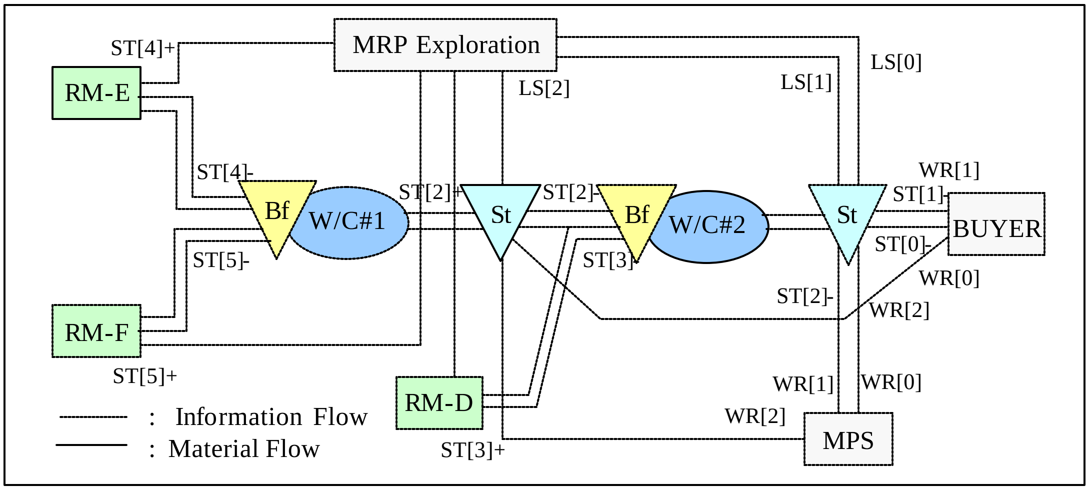


Figure 5: Diagram of MRP-push control system

MRP exploration converts the requirements of various final products into specific requirements of the subassemblies, components and raw materials needed by the final products. Moreover, feeder lines are designed to control part flows in the system by identifying component types and quantities on each operation of final products.

Figure 5 illustrates push control system for the same previous BOM structure. When an order is released, MRP exploration updates information about order (job type, lot size), and computes material requirements corresponding to an order lot (LS[]). Raw material authorized to be moved to the buffer immediately, the process starts as soon as any machines are available. Completed parts are moved to buffer for the next operation. WR[]+ denotes increase of order requirements, and WR[]- occurs when orders is delivered to buyer. The activities of stock inventory (ST[]'s) that occur between workcenter also happened in the same manner.

MRP system also determines the timing and size of order quantities to suppliers. A lot-sizing rule must be assigned to raw material types in advance. The choice of lot sizing rule proposed to the system is periodic fixed order quantities to smooth the production.

The MRP simulation model includes Data Input, Machine Capacity Planning, Lot Sizing, Order Releasing, and the Push Control System as shown in the Appendix B.

The model can be briefly described by taking a high-level view of the event graph. The push control mechanism of jobs is based on model of network of queue that have two basic activity cycles, one is used for controlling movements between resident entities (machines, stores, buffers), and the other is for controlling transient entities (jobs, raw material).

The activities on the FINISH, LINES, BUFFER nodes is designed to control part flows between workcenter, while the activities on JOINQ, BUFFER, START, FINISH, NEXTQ nodes present the status of machines (idle or busy), and changes between machine groups.

4 EXPERIMENT DESIGN CONSIDERATIONS

4.1 Experimental factors

Order release mechanism is based on planned demand that comes from confirmed orders and forecasted orders.

For the confirmed orders, the release is planned as a deterministic process, and rate of order release is uniform to smooth production. For the forecasted orders, the timing and quantity of orders is a stochastic process. Based on historical data, forecasted proportion can be estimated as a ratio of planned demand. In the study, forecasted order release is assumed with a predetermined rate, but probability of job release is estimated on scale of each forecasted job orders.

Table 1: Basic input data used in the hypothetical system

Order job	Job index	Processing time (hour)	Monthly demand	Forecasted proportion
A	0	0.5	7200	0.2
B	1	0.4	3600	0.1
C	2	0.3	1800	0

Processing time is assumed to be normally random variable with known mean, and standard deviation of 10% mean.

4.2 Experimental conditions

Each experiment includes 10 replications (runs) of length 1 day long. The independence of replications is accomplished by using different random seeds.

Simulation experiments are performed for three cases:

Case 1: "No variability". Simulation models are evaluated under deterministic environment where input and output processes are deterministic over time.

Case 2: "Processing time variability". Simulation models are evaluated under processing time variability. Processing times are assumed to be normally random variable with known mean, and standard deviation of 10% of the mean.

Case 3: “Processing time variability and Uncertainties in demand”. Simulation models are evaluated under processing time variability and uncertainties in demand where the standard deviation of demand is proposed as a fraction of monthly demand from MPS.

5 ANALYSIS AND RESULTS

5.1 Determining values of input factors

A heuristic procedure is employed to determine the number of Kanban in JIT model, and safety stock level in MRP model with predetermined upper bounds. An initial parameter set for each job includes 10 combinations, in which each combination requires 1 run for deterministic process (case 1), and 10 runs for stochastic processes (case 2 and 3).

Table 2: Values of input factors from heuristic results

JIT model	Number of Kanbans (A, B, C)			Output of jobs (A, B, C)			Total output
	KB[0]	KB[1]	KB[2]	OPUT[0]	OPUT[1]	OPUT[2]	
Case 1	5	7	23	240.0	120.0	60.0	420.0
Case 2	10	8	24	240.0	119.9	59.8	419.7
Case 3	11	10	28	239.7	119.9	59.8	419.4
MRP model	Level of safety stocks (A, B, C)			Output of jobs (A, B, C)			Total output
	SS[0]	SS[1]	SS[2]	OPUT[0]	OPUT[1]	OPUT[2]	
Case 1	15	9	1	240.0	120.0	60.0	420.0
Case 2	16	10	2	239.9	119.7	60.0	419.6
Case 3	17	13	4	237.6	121.2	60.0	418.8

Since the length of each run is 1 day long, the desired total output is 420 per day. Average total output is estimated from the experiments. A test with 5% significant level is performed to check whether the average at certain combination achieves the desired total output or not, a test with 5% significant level is performed. Table 2 shows results for the number of Kanbans, and safety stock estimated using the heuristic procedure.

5.2 Analyzing steady-state throughput

Welch’s procedure (1981) is employed to estimate a warm-up period. An experiment for case 3 is carried out by making 10 replications over 24 hours, and the throughput is observed every hour. The mean throughput is averaged value of 10 replications. The following graphs show mean throughput over 24 hour runs of JIT, MRP models.

A warm-up period of 4 hours is estimated for JIT, MRP models. Steady state mean hourly throughputs that estimate from average throughput of the last 20 hours are 17.095 for models.

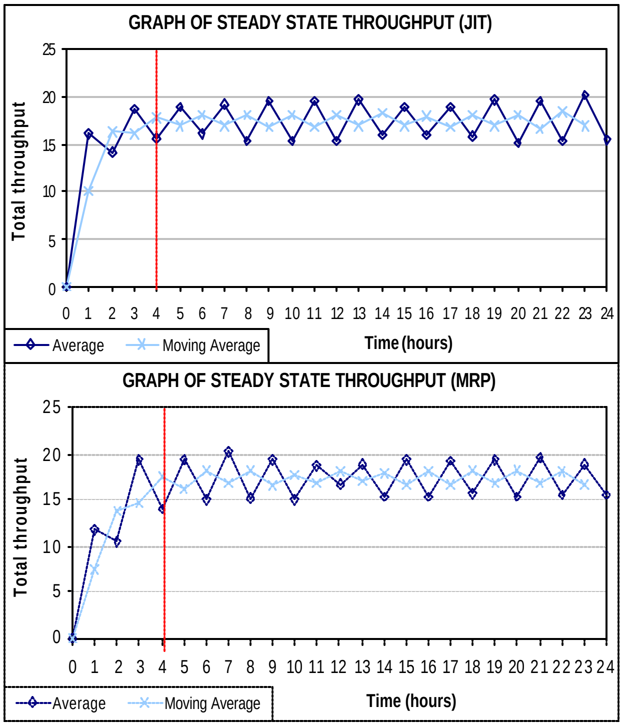


Figure 6: Graphs of steady-state throughput

5.3 Evaluating performance measures

To make a fair comparison, models are conducted in the same environment, and with the same values of input factors. Case 3, which is under processing time variability and uncertainty in demand, is chosen for evaluating performance measures between models.

Experiment with 10 replications with length of 1 day long and a warm-up period of 4 hours is employed to estimate throughput, time in system, and work in process. Experiment results are summarized in Table 3.

Table 3: Performance measures of the proposed JIT and MRP models

JIT MODEL	Average output	Throughput rate	Time-in-system	Average WIP
	OPUT	TPUT	TINS	AWIP
Job 0 (A)	240.0	9.839	1.285	12.689
Job 1 (B)	124.0	4.903	1.871	9.237
Job 2 (C)	60.0	2.503	0.689	1.727
MRP MODEL	Average output	Throughput rate	Time-in-system	Average WIP
	OPUT	TPUT	TINS	AWIP
Job 0 (A)	240.0	9.738	2.107	20.536
Job 1 (B)	121.9	4.942	2.380	11.799
Job 2 (C)	60.0	2.507	0.841	2.110

The hypothesis test assumes 5% significant level, and values of t-test are determined from level of significance and degree of freedom. Table 4 summarized mean and standard deviation of performance measures.

Table 4. Statistics for hypothesis testing of throughput and time in system

Through-put	Mean throughput		Standard deviation (STD)		Test statistic	Evaluation
	(JIT)	(MRP)	(JIT)	(MRP)		
Job 0 (A)	9.839	9.738	0.252	0.260	0.884	No difference
Job 1 (B)	4.903	4.942	0.155	0.122	-0.635	No difference
Job 2 (C)	2.503	2.507	0.003	0.004	-2.008	No difference
Time in system	Mean time in system		Standard deviation (STD)		Test statistic	Evaluation
	(JIT)	(MRP)	(JIT)	(MRP)		
Job 0 (A)	1.285	2.107	0.265	0.153	-8.493	Difference
Job 1 (B)	1.871	2.380	0.493	0.426	-2.473	Difference
Job 2 (C)	0.689	0.841	0.030	0.128	-3.650	Difference

By comparing values of t-test with test statistics, evaluations can be concluded from the comparisons. There are no significant differences on mean throughput between two models. However, average time in system of MRP model is greater than that of the JIT model.

6 SUMMARY

The success of the manufacturing system depends on both the design and operational factors associated with the system. The design factors that were studied include the number of machines for each group, values of input factor. While operational factors like processing time and uncertainties in demand were investigated in the study. From studied results, some findings are summarized as follows:

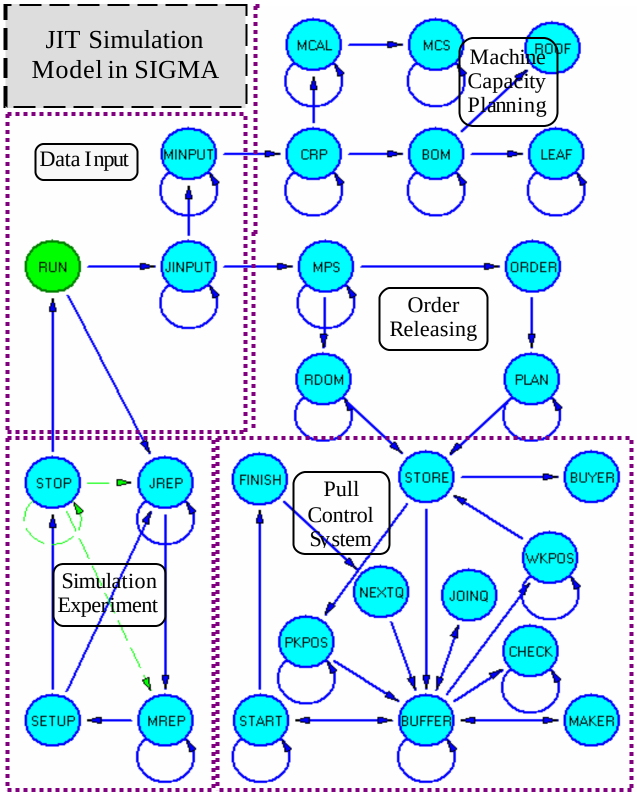
1. In highly stochastic environment, the system requires larger values of input factors to meet desired total output. It was observed that these values were assigned for parts differently in control systems. In the pull system, part with lower level in BOM structure that serves for many higher levels requires larger number of Kanbans. Meanwhile, in the push system, part with higher level that is processed through many stages (longer lead-time) requires larger safety stock.
2. The analysis also indicated that there exists an interactive relationship between the number of Kanbans and average WIP level in the pull system. Once the number of Kanban increases, average WIP also increases. The push system has a similar relationship between safety stock and lead-time.
3. In the same experiment environment, the average time in system of the push system is higher than that of the pull system. This also causes the higher WIP level in the push system. Another result is given that average machine utilization of the pull system is higher than that of the push. This concludes that the pull system is better to control activities on shop floor than the push system.

The study has some restrictions, and some recommendations for further research to refine and extend the capacities of methodology and reality are as follows:

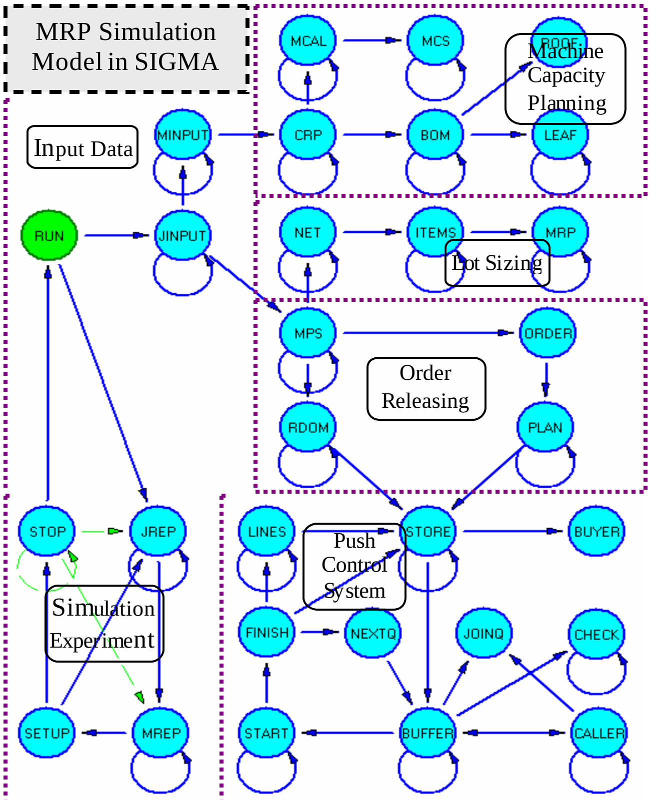
1. Many factors such as machine breakdown, load policies, contrasts of machine capacity, etc. should be included to study their effects.
2. The system was assumed a First Come First Serve (FIFS) rule in scheduling policy, and lot size of one unit for all stages in load policy. Future study should analyze changes in these policies that will affect the performance measures.
3. The study did not consider the system for multiple periods within a planning horizon. Since all values of variables are retained at the end of a period and use as input data for next one, the models can be extended to handle changes in product mix and volume.

The differences between the pull and the push system can be utilized as an advantage to build a manufacturing system that encompasses the positive attributes of the different mechanisms and to compensate for the weakness of both. The recommendation is to use MRP for planning and JIT for the execution in order to achieve an efficient manufacturing system.

APPENDIX A: JIT SIMULATION MODEL IN SIGMA



APPENDIX B: MRP SIMULATION MODEL IN SIGMA



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