Management of WIP Inventory in JIT Environment Under Cellular Layout - A Case Study

S. Venkataramanaiah*, K. Krishnaiah and R. Pichandi†

Industrial Engineering Division, Department of Management Studies, College of Engineering, Guindy, Anna University, Chennai - 600 025, India, E-mail: svr@annauniv.edu

In order to enhance the productivity and quality of products and services under the stiff competition in the global market, organisations are compelled to change their manufacturing technologies and strategies. One such strategy is to change the traditional layout into a cellular one to retain flexibility of jobshop and to bring in more related benefits. This paper discusses the effect of work-in-process (WIP) inventory on throughput rate in a cycle manufacturing company which switched over to a cellular manufacturing recently. A GPSS simulation model was developed to study the performance of the production system. For various models of the cycles, past data on demand, demand arrival time and process times were gathered from each cell. The distributions of these data were used and simulation was carried out for various combinations of WIP inventory with throughput rate as the performance measure. Finally WIP inventory levels for each cell were suggested for future production. Suggestions were also given for effective implementation of JIT strategies under cellular layout to improve the overall productivity. Indicators of a manufacturing system, where the technology was stable and the market structure was static and pre-defined, could be constructed upon the degree of production economy achieved. Normally, these are achieved through incremental innovations. Throughput, defined as the ratio of total satisfied demand to the total generated demand, and expressed as percent customer orders fulfilled, could be considered as an indicator of a stabilised manufacturing system. A related indicator that is somewhat dependent on the technology in operation was the ratio of WIP inventory levels at various cells/workstations to the throughput rate of the system, under throughput maximisation. The distribution of WIP along the cells and not the total WIP, was the most important process indicator under throughput maximisation.

Introduction

The core of Japanese productivity improvement in repetitive manufacturing is Just in time (JIT) philosophy. JIT concept proved effective in a pull production system that pulls material from a prior process in support of the final assembly. In conventional/pure push (Non JIT) production system facilities are arranged according to their generic process characteristics. Activities/jobs that require various resources will visit according to sequence of operations and leave the system. In conventional systems, planning takes place around some combination of forecasted demand and current actual customer orders. A production plan is developed that pushes through the manufacturing cycle and is generally less productive. In Cellular manufacturing, often referred to as the natural candidate for implementation of JIT and TQM, resources that are required to produce a product or set of similar products are arranged in a cell according to manufacturing requirements of parts. Cellular layout helps in achieving the goals of JIT and TQM. In JIT production system kanban cards are used to withdraw and produce the required parts/subassemblies. The objective of this paper is to design suitable work-in-process (WIP) inventory levels to maximise throughput rate/customer service in a cycle manufacturing company where JIT concept has been followed under cellular configuration.

Literature Review

Kanban based operational planning and control issues have been tackled in a number of studies1,4,5 based upon analytical and/or simulation modelling. Schroer et al.3, presented a microcomputer simulation study of JIT with Kanban based manufacturing system. It developed a simulation model using 'SIMAN' of a simplified JIT manufacturing system using one and two card kanban to vary the level of in process inventory in comparison with production rates. The work concerned with minimisation of WIP inventory at various
stock points in the system and to balance the system in terms of resource utilisation and queues. Mejabi\(^4\) described application of simulation constructs for JIT modelling and proposed a new language construct based on kanban satisfaction paradigm to provide required features for JIT simulation model for integrating new constructs into SIMAN language. Berkley\(^5\), discussed issues regarding minimum performance levels for Kanban controlled lines and methods to find minimum performance levels necessary to guarantee production rates independently by using average station processing time. Yavuz and Satir\(^6\), presented a Kanban based simulation study of a mixed model JIT manufacturing line and features of a hypothetical manufacturing line in terms of general structure, major components and operational characteristics. Researchers used simulation languages such as SIMAN, and SLAM to model the system and help in decision making. Since the organisation where the study was carried out was in the early stages of implementation of JIT strategies, a simple GPSS simulation model has been developed. WIP inventory levels at various stages in the production system have been designed and studied its effect on system performance, where JIT philosophy is followed under cellular configuration.

**Description of the production system**

The flow of material in the production system is shown in Figure 1. The system consisted ten manufacturing cells arranged in a line type of layout where JIT concept was followed. There were three production lines namely Frame, Fork and Mudguard, processed in parallel. Parts from these three production lines were grouped into a set of defined quantities at Kitting cell (#10). There were three major stages in the system, viz., kitting, finishing and phosphating. The objective was to meet the market demand with minimum WIP and finished goods inventory (FGI) at various stages in the system apart from the inventory at the raw material stage. As kitting cell was the last cell in production system, it acts as schedule driving cell for other cells. Bins and racks were used to transfer material from one cell to another. Whenever there was a demand, equivalent production was triggered. The kitting cell checked for required quantity and means to meet the generated demand. In case of shortage of required quantity at kitting cell, it gave signal to the previous cell and pulled required quantity if enough WIP inventory was available otherwise, that centre triggered its production. Other cells in the system, followed the same procedure.

**Problem Definition**

JIT production system helps increase inventory turnover and reduce equipment breakdowns, tool failures, problems in production planning and control. Excess inventory is an evil in JIT philosophy. Optimal or near optimal results can be effectively achieved by designing proper WIP inventory levels at appropriate stages in a system. A maximum total WIP in the system was no longer the goal. It was therefore necessary to evaluate the system by considering WIP inventory levels at all cells instead of treating the entire system as a single entity. The key point in JIT production system was that the system had to produce when there was a demand i.e., the generated demand should be satisfied by the system. Throughput, i.e., percent customer orders fulfilled (\(-\)Ratio of total satisfied demand to the total generated demand) was considered a suitable measure of performance to evaluate the JIT production system for various combinations of WIP inventory levels. Hence, the objective of the study was to set up suitable WIP inventory levels at various cells/workstations such that throughput rate of the system was maximized.

Inter alia, indicators of a manufacturing system, with the stable technology, static and pre-defined, market structure could be constructed upon the degree of production economy achieved. These were normally achieved through incremental innovations. Implementation of a JIT, with the objective of a minimised WIP inventory in a cellular production environment, came under the incremental changes. The changes through incremental innovation that could be achieved percentage included cost reduction, closer and deeper market-orientation of the manufacturing, amenability of the production to the demand fluctuation and finally, competition orientation. Throughput, was considered as a good indicator of a stabilised manufacturing system. A related indicator, somewhat dependent on the technology in operation, and hence whose use should remain limited to the benchmarking, was the ratio of WIP inventory levels at various cells/workstations to the throughput rate of the system, with a view of throughput maximisation. As claimed in this paper, it was the distribution of WIP along the cells and not the total WIP, that was the most important process indicator under the aim of throughput maximisation. These two indicators, could benchmark if limited to stable technology and competing manufacturing firms. Most important perhaps is the fact that these are process indicators. Most other indicators were either input or the output types. The suggested indicators referred to
the process internal systems and, therefore, were more suggestive of the dynamics of process parameters.

**Components of the system modeled**

Following are the some of the important components of the system modeled.

**Products** — The system was capable of producing six \((n=6)\) types of products (cycle), each type of product was handled in the system with Kanban (container) size of 200 units.

**Work Cells** — The production line was composed of ten \((k=10)\) work cells. The line was capable of producing six \((n=6)\) type of products. Each work cell had a processing capacity of one batch (size 200) at a time. Each cell in the system was designed by considering the processing requirements of various models that were produced. There were three main lines for frame, fork and mudguard, as shown in Figure 1.
Work in process (WIP) inventory — Any job in a queue, moving from one operation to the next, being delayed for some reason, being processed, or residing in the system or sub assembly inventories was considered as work-in-process (WIP) inventory, a special case of transit inventory. Each cell was equipped with both inbound and outbound stocking points. Storage space, and inventory carrying cost were considered as constraints on WIP inventory.

Finished Goods Inventory (FGI) — Each cycle had its own FGI. The final cell began its production to replenish the consumed containers of finished goods. The removal of a container from its WIP inventory triggered the manufacturing of that product. Hence, unless there was a demand, no production was initiated. External demand was satisfied from the inventories. If there was a dearth of sufficient number of items in FGI, the customer waited until the required amount was accumulated and it was measured as customer service which was strongly related with WIP and FG inventory in the system.

Operational Characteristics of the Model

Important operational characteristics of the system are given as follows:

- The system could be viewed either as a component of a composite manufacturing system, where production was carried out to satisfy the internal demand of the succeeding manufacturing cell, or a complete configuration in itself which produced to satisfy external demand.
- Time between demand arrival and demand satisfaction were the random variables which were generated from the appropriate distribution, based on the past data for each product/model.
- Each model/product followed the same processing route along the line.
- Production was triggered only upon the generation of a demand for a given product/model with no lost sales.
- For a given product, the production lot size was 200 units at each cell and hence production was carried out in batches. However, withdrawal of units from final assembly was in single units.
- Set up was required at a wash cell when different types of products were processed sequentially, set up times are constant at each work cell.
- A cell may suffer from breakdown. Time between breakdown and repair times were included in the processing time.
- Processing at a station was carried out with no defectives. Hence, a perfect quality conformation was assumed along the line.
- Continuous supply of raw materials was assumed. Therefore the first cell in the line never starved. Similarly continuous bought out components were assumed, therefore kitting cell never starved for bought out items.

Data Collection and Analysis

Data, such as demand and demand arrival time were collected from the past records for various models (cycles) including processing time at each cell. Inter-arrival time of demand, frequency of each day, inter-arrival frequency, and mean arrival time were calculated from the data. Mean demand, demand frequency/distribution was calculated using the following relation:

Let \( N \) be the sample size (No. of data collected), \( K \) be the number of classes, calculated using Strirge's rule

\[
K = 1 + 3.3 \log N.
\]

Length of each class was found using lower and upper value (LV and UV)

\[
\text{Difference (D)} = UV - LV\]

Range \( R = D / K \)

Class interval is calculated based on the range. Frequency \( (F) \) and mid value \( (X) \) of range \( i \) was calculated for the corresponding class interval and thereby probability distribution of each class interval was arrived at. Mean demand was computed using the relation,

\[
\text{Mean demand} = \frac{\sum F_i X_i}{\sum F_i}
\]

Simulation Model Development

Simulation model sought to duplicate behaviour of the system under investigation by studying the interaction among its components. The output of simulation model was presented in terms of selected measures (WIP, throughput/service) that reflected the performance of the system.

In the present study a GPSS model was built to design WIP inventory levels and to its effect on the system throughput was studied. GPSS maintained a simulation clock, schedules events to occur in future simulated time, caused the events to occur in a proper time-ordered sequence and assigned relative priorities used in resolving time ties. Production control system flow chart is shown in Figure 2.
The motivation in using GPSS model was its ability to understand the best known blocks and standard output, etc. The model was run at different simulation run periods and appropriate run length was selected based on simulated mean and actual mean for the collected data. Simulation run length used in the study was set as 30000 minutes of simulation clock time.

Model Frame Description

The following sections are used in the system for controlling purpose: Inter arrival time section (IAT), Demand generation section, Pull initiating section, and Satisfaction section.

Inter Arrival Time Section (IAT) — The inter arrival time followed an exponential distribution. IAT was calculated by the following relation.

\[ IAT_{\text{sample}} = (IAT_{\text{exp}}) \times [\log(1-RN)] \]

Where \( IAT_{\text{sample}} \) stands for the sample inter arrival time, \( RN \) uniform random number generator, and \( \log \) represents natural logarithm operator.

The log function was approximated with continuous GPSS function called EXAD, obtained by multiplying FNSEXAD with \( IAT_{\text{exp}} \). Thus the inter arrival time was generated using GENERATE Block.

Demand Generation Section — Based on the cumulative probability of demand, an appropriate demand function EXDD was defined. Using function EXDD demand was generated.

Pull Initiating Section — Whenever demand was generated, it was converted into number of lots. Split block created transactions, equivalent to the number of lots required. Thus pull was being initiated.

Demand Satisfaction section — Demand was satisfied by checking the inventory available at kitting cell (#10) or by drawing parts from preceding cells. Similarly other cells drew products from its preceding cell. Thus, demand was satisfied/customer order was filled.

GPSS Model Description (Working Mechanism)

The GPSS blocks used in the model were GENERATE, ADVANCE, SAVE, SPLIT, ASSIGN, TEST, TERMINATE, TABULATE, ENTER, and LEAVE. On generation of a demand, availability at cell #10 will be checked if enough number of units are available and demand would be met, otherwise the required quantity would be pulled from its preceding stage (finishing stage). Similar procedure would be followed at the other cells in the system. Once after dispatch of units, WIP at various cells would be updated by producing the quantity equivalent to the dispatched quantity (lots). A GPSS flow chart for the system under consideration was drawn with kitting cell and finishing stage along with frame line. Similar procedure was followed for mudguard and fork line. The step-wise procedure of GPSS model is given below:

- GENERATE Block generated a transaction based on the average inter arrival time \( (IAT_{\text{exp}}) \) and the GPSS inter arrival time function \( (FNSEXAD) \).
- VSDMND generated the demand and saved in SAVEVALUE block.
- TABULATE block tabulated the demand.
- SAVEVALUE Block calculated the total demand \( (x1) \) by adding the demand generated in the previous Block.
- At TEST block generated demand would be compared with the WIP at cell 10 and met if enough WIP was available. If WIP at cell was less, it would pull from its preceding cell(s). SAVEVALUE block saved the unfilled demand in a variable (UDF).
- Variable V$DNK converted the demand into number of lots and stored remainder quantity in the remainder quantity variable, V$REMAIN.
- SPLIT block propagated transactions equivalent to the number of lots.
- The ENTER Block acted as BIN for the WIP at the kitting cell. Whenever the Block was free, it allowed a transaction to enter in it; otherwise the transaction stayed in the previous block itself.
- Once the transaction entered in the ENTER block, TEST block checked the WIP in all immediate preceding cells. If enough WIP was available, kitting cell pulled the WIPs, completed the operation and released the BIN. If the immediate previous cell WIP was not sufficient to satisfy the requirement of the kitting cell, previous cells pulled the WIPs from its immediate previous cells.
- GENERATE block generated a transaction at a specified time to complete the simulation.

Results, Conclusions and Future Scope of Work

Results — Simulation experiments were conducted for different simulation run periods. Base simulation run period was selected from the analysis by comparing simulated mean and actual mean. The model was simulated for the base simulation run period by keeping zero WIP inventory at all cells. Similarly the WIP at
all cells were increased by 200 units, and repeated trials were conducted by increasing the WIP by 200 units equally at all cells. Throughput rate (per cent service) was calculated for these trials. From these trials, limit on WIP inventory was found to be 0 - 600 in steps of 200 and results of the trials are given in Table 1.

Taking minimum WIP as 0 and maximum WIP as 600 units in steps of 200 units, various combinations of WIP were obtained using the model. Simulation was run for 500 combinations of WIP inventory levels. Sample results are given in Table 2 with associated WIP inventory levels. Three combinations gave above 99 per cent service level. WIP inventory kept at different cells for combination A was 1800 units, for B 3000 units and for C 2800 units. Combination A gave the least inventory to be kept and it was chosen as the better combination among A, B and C. Combination E resulted in the lowest throughput with high WIP than combinations A, D and F. From the results obtained, it is apparent that the overall system performance was affected by the distribution of WIP inventory at various stages in the system. Combination A gave the lowest WIP with 99.78 per cent throughput whereas combination F resulted in the lowest throughput of 57.62 per cent for the same WIP level. Combination B and C showed the same throughput of 99.90 per cent at different WIP levels. Alternative D and F showed the same throughput of 57.62 per cent with WIP at 2000 and 1800, respectively.

Even though F and A had the same total WIP inventory (1800), combination A gave a better throughput rate with service rate 99.78 per cent compared to the combination F with service rate 57.62 per cent. It showed that the distribution of WIP at various stages in the system was more important unlike the total WIP. Hence combination A is recommended as suitable WIP inventory at different cells in the system based on the performance measure used.

Conclusions

As the company changed its layout from traditional (process) to cellular layout with JIT concept, the future production could be planned based on these guidelines. It was believed that this kind of simple management tool would help the manufacturing concerns to
improve their overall productivity, significantly but incrementally.

The indicators, of a manufacturing system where the technology is stable and the market structure is static and pre-defined, can be constructed upon the degree of production economy achieved. Ordinarily, these are achieved through incremental innovations. Implementation of a JIT, with the objective of a minimised WIP inventory in a cellular production environment, falls under the incremental changes. Throughput, defined as the ratio of total satisfied demand to the total generated demand (per cent of customer orders fulfilled), could be considered a good indicator of a stabilised manufacturing system. A related indicator, somewhat dependent on the technology in operation, and hence whose use should remain limited to the benchmarking, is the ratio of WIP inventory levels at various cells/workstations to the throughput rate of the system, under throughput maximisation. As claimed in this paper, it was the distribution of WIP along the cells and not the total WIP, that was the most important process indicator of throughput maximisation. Continuous updating of databases can be incorporated so as to accommodate as many customer orders as possible into the production schedule. Line balancing studies (in preceding and succeeding departments) can be conducted for uniform cycle time (minimum idle time) in the production system. GPSS model parameters are required to be updated based on the actual demand. Model can be updated by considering variable setup time, breakdown time and rejection rate, etc. Alternate simulation models can be developed and compared and suitable model can be selected.

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About the authors

S Venkataramanaiah. Currently working for his Doctoral degree in the area of Cellular Manufacturing. Currently he is on a one year assignment at Indian Institute of Management, Bangalore working on a sponsored Research Project entitled “Managerial frame work for implementation of Cellular Manufacturing – In Indian Context”. He has presented several technical papers at national and international level conference in the area of POM. Industrial Engineering Division, Department of Management Studies, College of Engineering, Guindy, Anna University, Chennai, India 600 025

K Krishnaiiah is Head of the Industrial Engineering, who had about 6 years of industrial experience and 19 years of teaching experience. His articles appeared in national and international journals and presented several papers at national and international conferences. His areas of interest include TQM, work design/ergonomics, Operations Management & CIMS. Industrial Engineering Division, College of Engineering, Guindy, Anna University, Chennai, India 600 025

R.Pichandi is Auditor-Software quality in the area of Y2K implementation as Asst. System Engineer, 560 052