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Optimal Performance Enhancement Using JIT Manufacturing System Simulation Model

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ABSTRACT

JIT Manufacturing System is a suitable means for a company that wants to perform in a competitive market This study used a simulation modeling methodology to design a JIT system for drug process plant. It equally examined the impact of different manufacturing system alternatives, manufacturing overhead levels, and product mix complexity levels on manufacturing performance measures. The manufacturing performance measures examined included internal and external as well as financial and non-financial measures of success. These measures were demand fulfillment rate, cycle time, and net operating income. In order to develop a more realistic model by containing other items or more complex factors, other Kanban items and non-Kanban items are included together with the trial item as well as factors that are significant to the operation of the system such as arrival time, batch sizes or waiting time. Not all items produced by the Drug Process Plant were simulated due to software limitation and the scope of the study. Four major items covering 54% of the total order that place the four highest ranks in terms of values are selected for the simulation. The results present particularly interesting implications for manufacturing systems. The increase of demand for more complex and higher priced products presents an opportunity for increased revenues. Higher levels of manufacturing overhead had no significant effect on the product mix decision; however, total costs and differences between the various manufacturing system alternatives are improved. As the manufacturing overhead level setting increases, the slope of the cumulative net operating income curve decreases. The implication for both management and engineers is that the choice of manufacturing system alternative becomes increasingly important as product mix complexity increases and may be amplified as manufacturing overhead levels increase. Material Resource Planning System (MRP) begins to significantly outperform the other two manufacturing system alternatives at a medium demand setting for product mix complexity. This difference becomes more pronounced as product mix complexity is set at a high level. At this high setting, Just in Time Manufacturing System (JIT) begins to slowly outperform Mass Production System (MPS).

Keywords: *Flow, Pull, Non-Kanban Items, Kanban Items, Average Demand Fulfillment Rate, Average Cycle-Time, Average Net Operating Income*

1.0 INTRODUCTION

JIT manufacturing entails the production of goods based on demand. It contradicts the usual American manufacturing ideal of producing as much inventory as possible in expectation of demand. Ideally, JIT gets rid of all work-in-progress, and produces only goods that are immediately needed. Manufacturing Resource Planning (MRP) system and the Mass Production System (MPS) cannot respond quickly enough to the product design changes. This results in, amongst other things, high levels of obsolete stocks.

This is asuitable means for a company that wants to perform in a competitive market. Some potential benefits that can be obtained by applying JIT concepts include: significant reduction of setup time, reduced cost of quality (such as scrap/rework reduction), increased inventory turn-over, increased manufacturing flexibility and shorter lead time. Companies operating in highly competitive environments are the most appropriate for employing JIT concepts. JIT is founded on the pillars of: A) Implementation of Flow, and B) Implementation of Pull. Advance analysis of these pillars is presented below:

1.1 Implementation of Flow

In order to establish flow in a system, three preconditions must exist, which are discussed below:

a) Setup Time Reduction

The method of Setup time reduction or Single-Minute-Exchange-of-Dies (SMED) comprises five steps:

Maintenance, Organization, and Housekeeping. A typical cause of setup problems is poor housekeeping, poor equipment maintenance and incorrect organization of tools. Proper maintenance, organization, and housekeeping are easy to be enforced and result in significant benefits.

Separate Internal elements from External and convert them to External. Internal (or mainline) elements are the processes that occur when the machine is not working, while external (or offline) elements are the processes that can be worked out while the machine is operating. The notion here is to convert as many internal elements as possible to external. Chief among internal elements that can be converted to external are searching time looking for the correct die, tools, carts, etc, waiting time for instructions, carts etc, and setting times for setting dies, fixtures, etc.

Improve Elements. Examine of each element and try to find methods of eliminating waste. 4. Eliminate Adjustments. A short period of time is required to enforce a new adjustment but a long period of time is required to make this adjustment to function properly.

5. Abolish Setup. This composes the ultimate goal of the SMED method and it could be achieved by either redesigning the products and make them uniform, so the same parts are required for various products or producing various parts in parallel at the same time (Black and Hunter, 2003; Hopp and Spearman, 2001; Hay, 2008). b) Quality at the Source

Quality at the Source according to JIT constitutes of two main principles: Total Productive Maintenance (TPM), and Total Quality Management (TQM). TPM includes the techniques of preventive maintenance, predictive maintenance, improvement maintenance, and 5Ss maintenance while TQM include standardized work, visual control, poke yoke, and kaizen. c) Cellular Layout

Cellular Layout is the organization of the manufacturing facility (people, materials, machines, and design) in cells, dedicated or semi-dedicated in product families.

1.2 Implementation of Pull

The pull production system according to Crabill (2016) is defined as a two subsystem linkage in a supply chain. The producing operation does not produce until the standard Work-InProcess (WIP) between the two sub-systems is less than the set point. When the standard WIP is below the set point, this condition signals the need to replenish. Information flows in the reverse direction from product flow to signal production by the upstream cell or manufacturing process.

Pull embodies a production system that explicitly limits the level of WIP in contrast to the push production system (Hopp and Spearman, 2001). According to Smalley (2014), three main types of pull systems exist: the replenishment pull system in which production is triggered when the stored end items are consumed, the sequential pull system in which the production rate is regulated according to the demand with the pacemaker to be usually established in the first process step at the beginning of the value stream map, and the mixed pull system, which is the combination of the replenishment and the sequential pull systems.

In order to implement pull, as it was shown earlier, Flow must be established. After that a series of three additional techniques can be applied in order to realize pull production. These techniques are described below: a) Level Production

Level or Smoothing Production attempts to eliminate fluctuation in final assembly by eliminating variation or fluctuation in feeder processes. It represents a scheduling technique for balancing a production line by changing a) the production volume; i.e. parts are produced one single-piece at a time, and b) the production sequence of parts.

Level production can improve the line performance by specifying which products are to be produced at each time interval. It is often preferred to implement level production firstly in the assembly operations, and secondly to adjust the cycle time to be equal or slightly less than the takt time.

The Japanese fashioned a visual scheduling tool called the heijunka box. Heijunka is generally a wall schedule, which is divided into a grid of boxes, each one representing equally established time intervals during shifts which indicate what products and in what quantity should be produced during the corresponding time interval. In this box, daily orders (kanbans) are introduced by production control in order to pull products of the right mix and provide instructions to the system about sequential planning. Additional information for leveling the production can be found in the work of Black and Hunter (2003) as well as in Smalley (2014).

Kanban Technique

The lean method of production and inventory control is a pull system generally known as the kanban system (kan means signal and ban means card in Japanese). Kanban cards denote a visual control tool that regulates the flow of materials between cells and aim to respond to demand by delivering parts and products Just-in-Time. Hence, it is a method of controlling the flow of information between the workstations while eliminating the WIP levels. In general, the kanban method functions as described in the subsequent paragraph:

The downstream customer, either internal or external, pulls parts (downstream flow of parts) from the upstream supplier (internal or external) as required. Empty product containers are indicators (upstream flow of information) for replenishment. The above is carried out by using different kinds of kanban cards, such as production cards, move or withdrawal cards, signal cards, etc. and it comprises a significant method of production control and controlling levels of WIP.

Development of Supplier Networks

Lastly, according to the literature on JIT, supplier networks must be developed. The integration of suppliers seeks to transfer the technological knowledge from the customer to the supplier and convert the latter to a lean manufacturer. As a consequence, suppliers evolve into remote cells in the linked-cell manufacturing system and deliveries are becoming synchronized with the buyer's production schedule.

The supplier networks must consist of fewer and better suppliers and the contracts should be long-term and mutually beneficial. The rule here is to create single sourcing supplies for each component or subassembly by certifying the related suppliers (Black & Hunter, 2003; Wu, 2013; Waters-Fuller, 2011; Hay, 2008).

2.0 METHODOLOGY

Basically, the objective of this stage is to develop a more realistic model by containing other items or more complex factors. In this model, other Kanban items and non-Kanban items are included together with the trial item as well as factors that are significant to the operation of the system such as arrival time, batch sizes or waiting time. The complete listing of the model i.e. model.mod and model.exp can be shown in the Appendix.

2.1 Selection of Items to Be Simulated

As previously explained, not all items produced by the Drug Process Plant will be simulated due to the limitation of the software and the scope of the study; therefore, selecting items in the simulation is essential. Based on the investigation, only 78 of items have periodical order quantities of more than 100 units or values less than ₦40000. Four major items covering 54% of the total order that place the four highest ranks in terms of values are selected for the simulation i.e. TVM 1137797/R11, TVM 113277/R3, TVF 113666/R24 and TVM

1137627/R9. In the model, all these items are considered as Kanban items. Although these items have not yet been determined as Kanban items, the Drug Process Plant is highly likely to choose them as Kanban items due to the volume of these items. The rest (i.e. 74 items) is represented by four hypothetical items that will have the same characteristics in terms of production orders and processing time. These items are considered as non-Kanban items since the orders are low.

2.2 Determination of the Arrivals of Orders

There are two types of items included in the model. a. High-Volume Kanban Items

High volume Kanban items arrive weekly and each item is understood to have the same chance to arrive. So, arrival time of these items is as follows:

24 (hours) x 7 (hours) x 60 minutes = 10080 minutes

Given that four items are created within a week, the uniform distribution of these items is: 10080/4 = 2520 minutes. If the deviation of arrivals is assumed to be around 20%, the uniform distribution of these items is UNIF(2520,3024).

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Based on this information, in the model file, the arrivals and the proportions of the order quantities can be written in SIMAN as follows:

```
CREATE : UNIF(2520,3024):  MARK(Arrtime2);
  ASSIGN :  Type=DISC(.25,5,.5,6,.75,7,1.0,8); ! arrivals of high-volume Kanbans
```

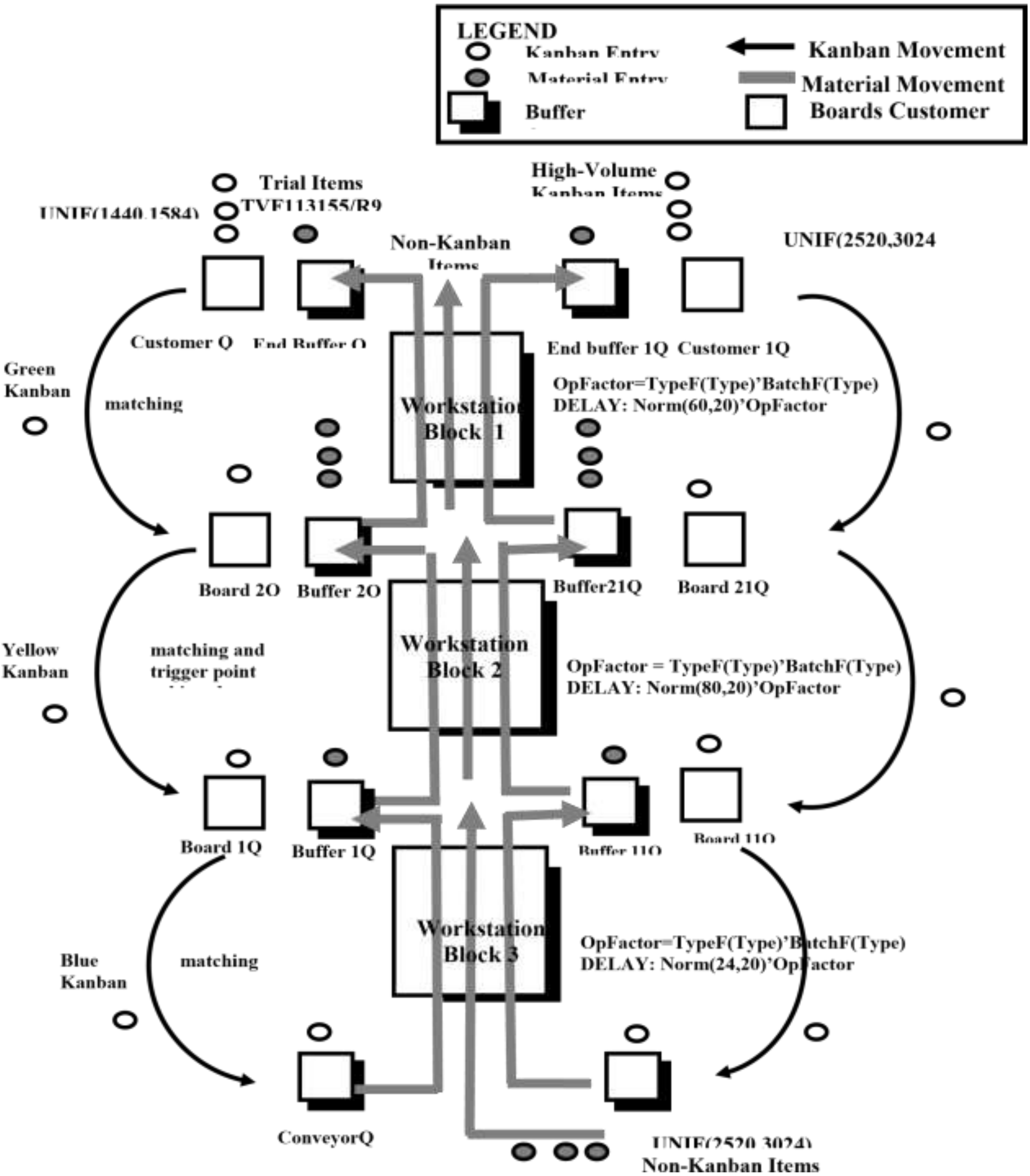

Figure 1: The flow of entities in the model

b. Non-Kanban Items

Four non-Kanban items are included to represent 74 items. Even though the order of each item represented has a different periodical arrival time, the items are assumed to be weekly items like the high-volume Kanban items. Since the total waiting time for 74 items cannot be represented in these items, this factor will be taken into account later in determining the processing time. Based on the above information, the arrivals and the proportion of the order quantities can be written as follows:

CREATE : UNIF(1440,1584,2): MARK(Arrtime3);

ASSIGN : Type=DISC(.25,5,.5,6,.75,7,1.0,8); ! arrivals of non-Kanban items

Non-Kanban items move directly from one workstation to another workstation according to the push system. In simulation, the entities representing the materials move directly in the opposite direction from block 1 to block 3 without waiting the arrival of Kanbans. The entities may wait at a workstation if the resource is busy.

The entity flow in the model that includes the trial items, the high-volume Kanban items and the non-Kanban items can be described as Figure 1.

2.3 Processing Time

The order quantity and the type of items are employed to calculate the processing time for the high volume and non-Kanban items. In the model file, both factors are identified as multiplying factors called BatchF and TypeF in that order. In view of the fact that the processing time and the order quantity of the trial item TVF 113155 are known, the standards for calculating the factors are based on this item.

In the model, the value of BatchF and TypeF for TVF 113155 are equal to 1. Basically, BatchF is determined based on the total production volume and the capacity of the mixing/blending machine. It is determined in the following steps. The original order quantity of the trial item in the push system is 360 units and the total production in the second semester is 4652 units. Since the order of the trial items is weekly, there are 4652/360 weeks or around 13 weeks to replenish the orders. Therefore, if the high-volume item TVM 1137797/R11 is a weekly order item and the total production is 18000 units, the order size of this item is 18000/13 or around 1380 units. Because of the setup time of mixing/blending machines, the optimal batch size is 120 units so the weekly order for this item is rounded into 1320 units (a multiple of 120). Therefore, BatchF is 1320/360 or 3.7.

TypeF is determined directly according to the processing time of the items. For instance, the tablets have a processing time of around 1.5 of the capsules, therefore, TypeF is 1.5. For the non-Kanban items which each represents 8 smaller items, TypeF is 5.0 to contain the effects of the waiting and queuing time required to process this item. Table 1 summarises factors of each item.

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Table 1: The values of BatchF and TypeF

GROUP	ENTITY	BATCH SIZE FACTOR (Batch F)	FACTOR OF ITEM TYPE (Type F)
Trial Items TVF 113155	30- unit-order item	1.0	1.0
	60-unit-order item	1.0	1.0
	90-unit-order item	1.0	1.0
	120-unit-order item	1.0	1.0
High-Volume Kanban Items	TVM 137797/R11	3.8	1.5
	TVM 113277/R3	6.0	1.5
	TVF 113666/R24	5.0	1.0
	TVM 1137627/R9	2.0	1.5
Non-Kanban Item	Non-Kanban Item 1	3.3	5.0
	Non-Kanban Item 2	3.3	5.0
	Non-Kanban Item 3	3.3	5.0
	Non-Kanban Item 4	3.3	5.0

In SIMAN, the value of all multiplier factors is represented in the experimental file as the following list:

```
VARIABLES : TypeF(12),1.0,1.0,1.0,1.0,1.5,1.5,1.0,1.5
                5.0,5.0,5.0,5.0:
            BatchF(12),1.0,1.0,1.0,1.0,3.8,6.0,5.0,2.0
               3.3,3.3,3.3,3.3;
```

These variables are then used to calculate the processing time at each block as shown in the following list of the model file:

```
Block2  QUEUE,    Workstat2Q;
        SEIZE :   Workstat2;
        ASSIGN :            OpFactor=TypeF(Type)*BatchF(Type);
        DELAY :   Norm(240,10)*OpFactor;
        RELEASE : Workstat2;
```

From a modeling point of view, the Kanban triggers the change of status of the system. Another element regarded as an entity is material. Material is not necessarily represented as an entity and this depends on the approach used for modeling the system. However, by considering the materials as entities, the movement of the materials can be observed through animation.

Animation is a dynamic display of graphical objects, shapes or colours on a static background (Pegden et al.,2011). In this research work, the purpose of the animation is to verify the logic of the simulation. The role of animations in JIT simulation is substantial particularly in reducing the time required to verify the model. Some common logical errors which include forgetting to initialise variables and failing to release resources after finishing an operation can be easily

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observed using animation. In addition, often a model that seems reasonable during the modeling phase may be too simplistic in animation, therefore, some modifications are required to improve the accuracy of the model.

Parts are shipped from the production sub-model to the consumption sub-model. In transit, they go through the supplier sub model (figure 3). Kanban controls the reordering of parts. All kanban cards start and end in the kanban sub-model (figure 4). Parts and kanban cards from the supplier sub-model are transported to the plant sub-model. Cycle entities signal the transport cycles and they only exist in the route sub-model (figure 2); they specify the time to dispatch.

Figure 2: Route Sub Model

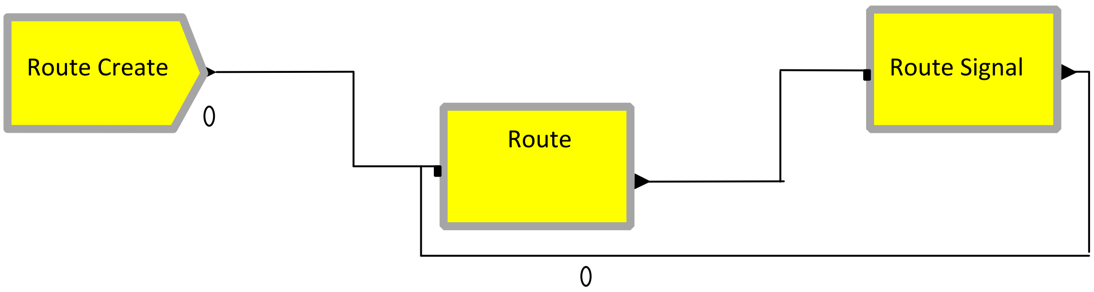

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Figure 3: Supplier Sub Model

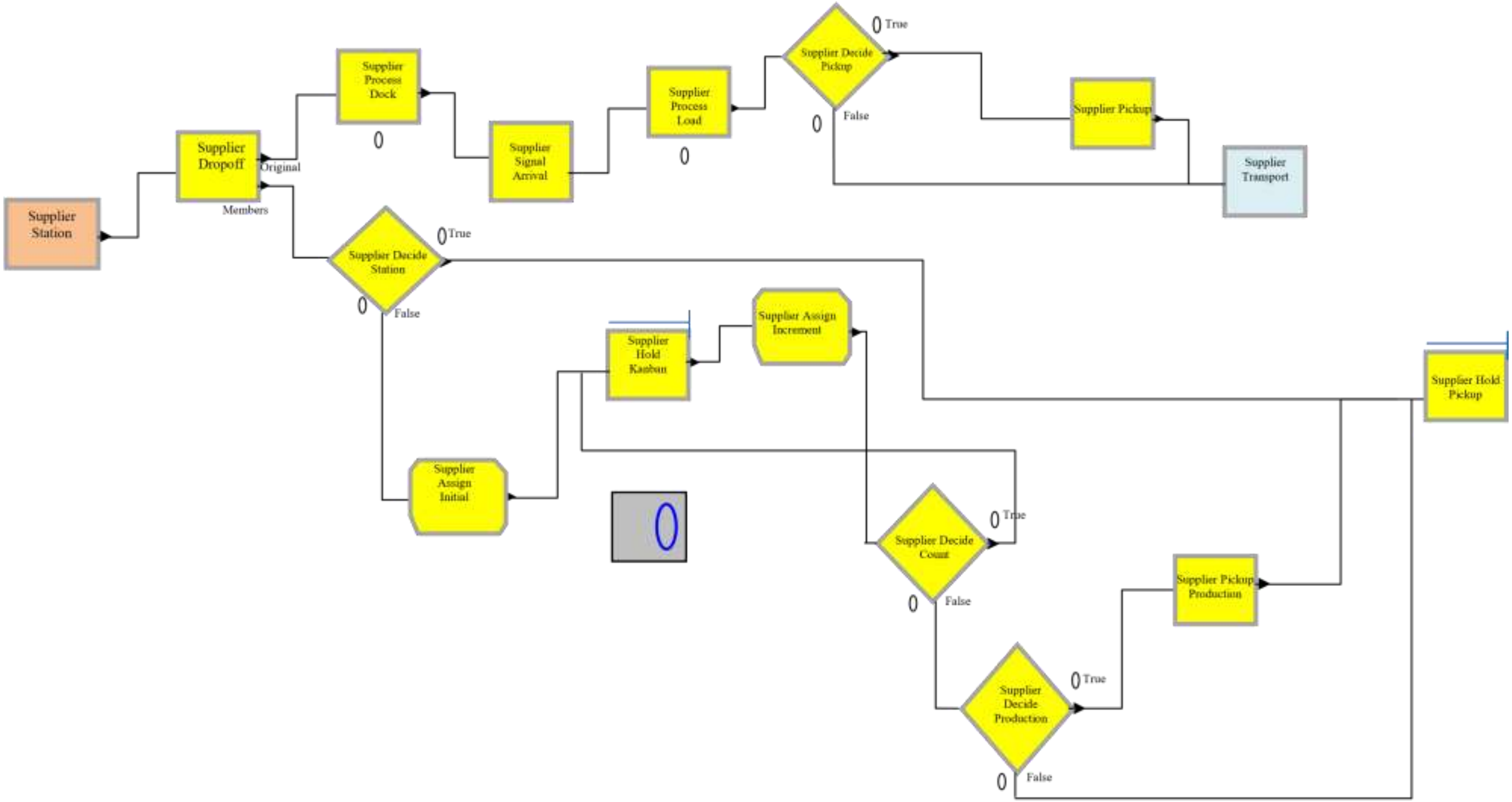

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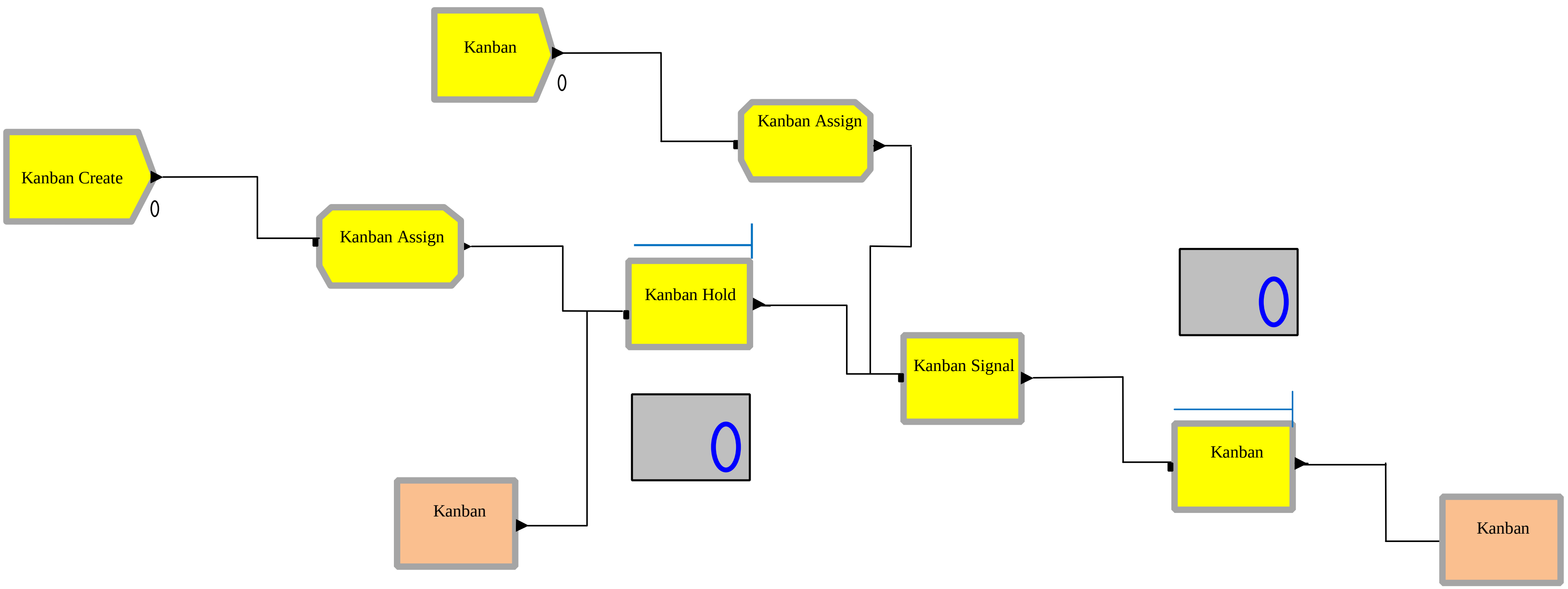
Figure 4: Kanban Sub Model



3.0 RESULTS

This study used a simulation modeling methodology to design a JIT system for drug process plant. It equally examined the impact of different manufacturing system alternatives, manufacturing overhead levels, and product mix complexity levels on manufacturing performance measures. The manufacturing performance measures examined included internal and external as well as financial and non-financial measures of success. These measures were demand fulfillment rate, cycle time, and net operating income. Table 2 below summarizes the results of this study in terms of these three manufacturing performance measures by manufacturing system alternative and combined weighted score.

Table 2: Summary of MAS Performance by Experimental Condition Group

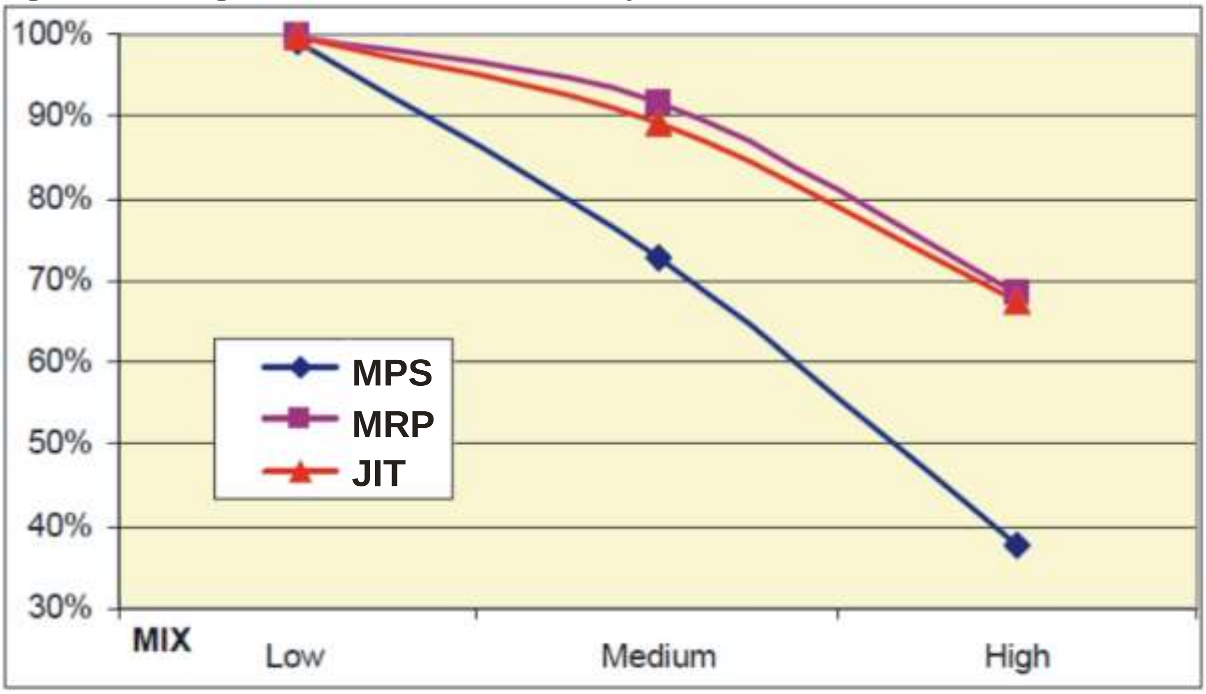
MOH Level	MIX Level	Performance Measure											
		Demand Fulfillment Rate			Cycle Time			Net Operating Income			Combined Weighted Score (Maxium 6)		
Low	Low	1	MRP	99.8%	1	JIT	304.91	1	MRP	86.188	1	MRP	5
		2	JIT	99.6%	2	MRP	305.13	2	MPS	85.660	2	JIT	3
		3	MPS	99.2%	3	MPS	326.38	3	JIT	85.603	3	MPS	2
	Medium	1	MRP	91.6%	1	JIT	549.88	1	MRP	105.922	1	MRP	4
		2	JIT	89.1%	2	MPS	698.46	2	MPS	101.416	2	JIT	3
		3	MPS	72.6%	3	MRP	745.55	3	JIT	101.405	3	MPS	2
	High	1	MRP	68.5%	1	MPS	608.89	1	MRP	115.412	1	MRP	4
		2	JIT	67.5%	2	JIT	619.20	2	JIT	103.579	2	JIT	3
		3	MPS	37.7%	3	MRP	670.13	3	MPS	101.771	3	MPS	2
Medium	Low	1	MRP	99.8%	1	JIT	304.91	1	MRP	78.087	1	MRP	5
		2	JIT	99.6%	2	MRP	305.13	2	MPS	77.803	2	JIT	3
		3	MPS	99.2%	3	MPS	325.38	3	JIT	77.480	3	MPS	1
	Medium	1	MRP	91.6%	1	JIT	548.21	1	MRP	100.462	1	MRP	4
		2	JIT	89.1%	2	MPS	698.46	2	MPS	95.799	2	JIT	3
		3	MPS	72.6%	3	MRP	745.55	3	JIT	95.319	3	MPS	2
	High	1	MRP	68.5%	1	MPS	608.89	1	MRP	112.319	1	MRP	4
		2	JIT	67.5%	2	JIT	619.15	2	JIT	98.462	2	JIT	3
		3	MPS	37.7%	3	MRP	670.13	3	MPS	96.620	3	MPS	2
High	Low	1	MRP	99.8%	1	JIT	304.91	1	MRP	53.781	1	MRP	5
		2	JIT	99.6%	2	MRP	305.46	2	MPS	53.507	2	JIT	3
		3	MPS	99.2%	3	MPS	326.38	3	JIT	53.258	3	MPS	1
	Medium	1	MRP	91.6%	1	JIT	548.88	1	MRP	76.283	1	MRP	4
		2	JIT	89.1%	2	MPS	698.46	2	MPS	72.467	2	JIT	3
		3	MPS	72.6%	3	MRP	745.89	3	JIT	71.352	3	MPS	2
	High	1	MRP	68.5%	1	MPS	608.89	1	MRP	89.038	1	MRP	4
		2	JIT	67.5%	2	JIT	618.94	2	MPS	74.866	2	MPS	3
		3	MPS	37.7%	3	MRP	670.13	3	JIT	74.744	3	JIT	2

The combined weighted score is a composite measure of the three primary manufacturing performance measures, whereby two points are assigned to the best performing manufacturing system, one point to the second best performance, no points to the worst performance. Therefore a perfect score of 6 would indicate that the manufacturing system scored the highest along all three manufacturing performance measures. As can be seen in Table 2 above, no single manufacturing system excelled across all three measures indicating that each alternative has its own limitations in terms of performance that must be considered in decision making. This is an important point to note, especially for manufacturing systems.

As can be seen in figure 5 below, all three manufacturing system alternatives performed nearly equally well when the product mix complexity (MIX) was low. As product mix complexity increased, all three saw a decrease in demand fulfillment rate.

However, the falloff in demand fulfillment rate occurred at a far greater rate under Mass Production System (MPS) as compared to the two other manufacturing system alternatives. Although Material Resource Planning System (MRP) performed the best across all levels of product mix complexity, Just in Time Manufacturing System (JIT) performed nearly as well along this crucial customer service measure.

Figure 5: Average Demand Fulfillment Rate by MAS



Because a major focus of this study was to examine the impact of manufacturing system alternatives within the context of today's increasingly time-based competitive environment, the internal manufacturing performance measure of cycle time is of primary importance. As discussed earlier, cycle-time is the primary success measure for a time-based competitor. In terms of this strategic measure, Just in Time Manufacturing System (JIT) performed the best at nearly all setting of product mix complexity.

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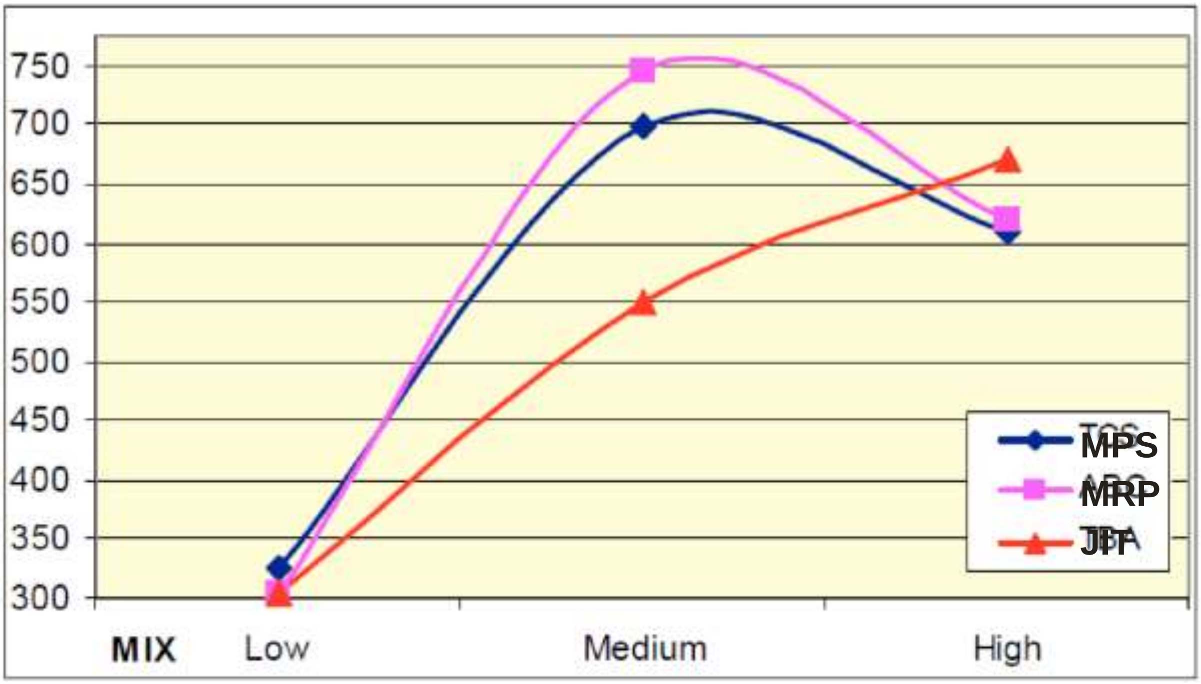
Just in Time Manufacturing System (JIT) drove a product mix decision that better balanced the manufacturing line and resulted in the lowest average cycle-times for all products. It is interesting to note that Material Resource Planning System (MRP), which generally outperformed vis-à-vis the other two manufacturing performance measures, was least effective in terms of cycle times.

It is important to note that the variability of cycle-times across the various levels of product mix complexity was much less than the variability under the Mass Production System (MPS) and Material Resource Planning System (MRP). This may have important implications for the time-based manufacturer that is concerned with consistently delivering faster cycle times under varying levels of product mix complexity demanded by the market.

Figure 6: Average Cycle-Time (Minutes) by MAS



Net operating income is the only financial measure of manufacturing success included in this study, and an argument could certainly be made that it is the bottom line and the most important measure. Figures 7 through 9present the average net operating income measures for the various manufacturing system alternatives under differing levels of product mix complexity demand and differing levels of manufacturing overhead. Material Resource Planning System (MRP) clearly outperformed the two other manufacturing system alternatives along this measure. Mass Production System (MPS) and Just in Time Manufacturing System (JIT) performed nearly equally well under low and medium demand settings for product mix complexity. As the product mix complexity increases; however, Mass Production System (MPS) begin to fall behind Just in Time Manufacturing System (JIT).

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Figure 7: Average Net Operating Income by MAS
(Low Manufacturing Overhead Level)

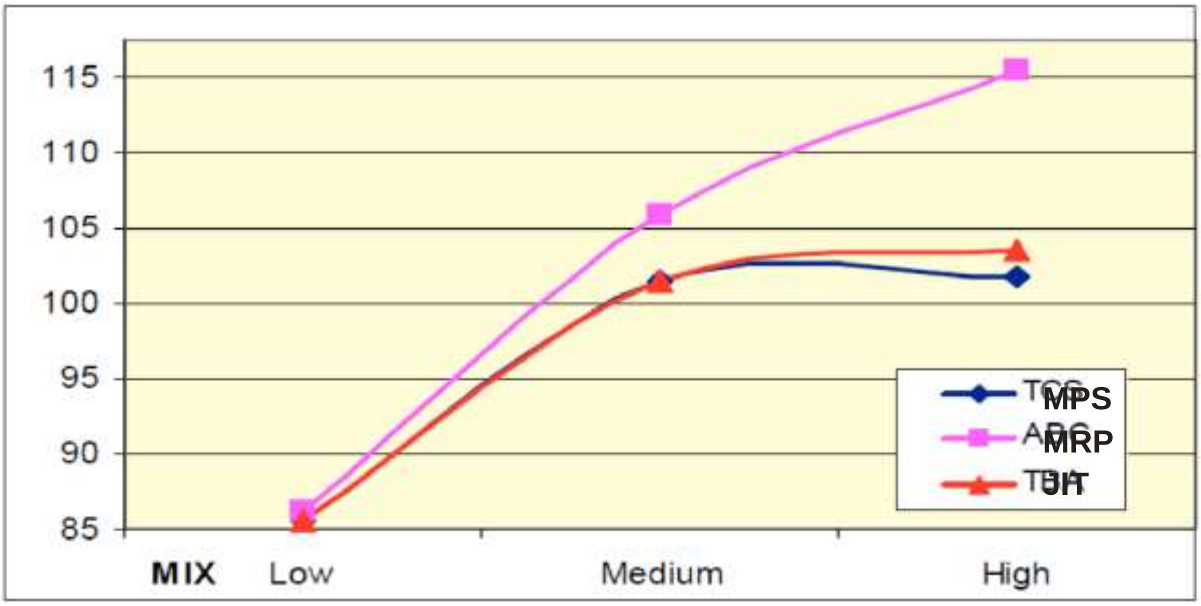

Figure 8 below shows essentially the same results, with Material Resource Planning System (MRP) clearly outperforming the other two manufacturing system alternatives. The difference between Mass Production System (MPS) and Just in Time Manufacturing System (JIT) again is not as great under medium levels of product mix complexity but increases with high levels of product mix complexity.

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Figure 8: Average Net Operating Income by MAS (Medium Manufacturing Overhead Level)

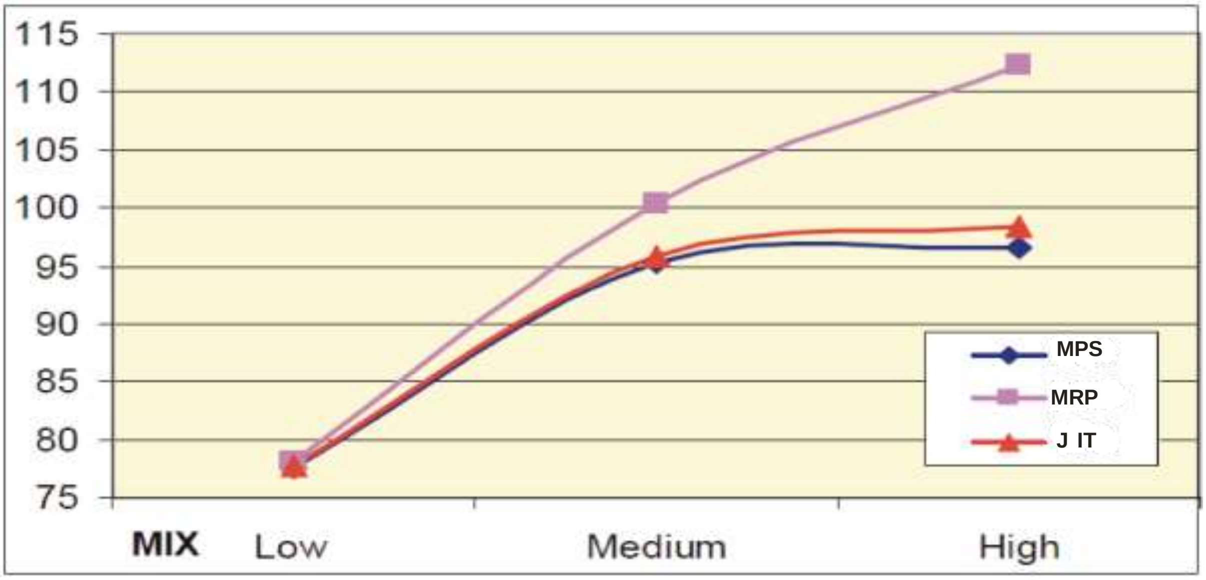

Figure 9 again shows very similar results, with Material Resource Planning System (MRP) clearly outperforming the other two manufacturing system alternatives. Overall, average net operating income is at its lowest given the higher levels of manufacturing overhead. The difference between Mass Production System (MPS) and Just in Time Manufacturing System (JIT) again is not as great under medium levels of product mix complexity but increases with high levels of product mix complexity.

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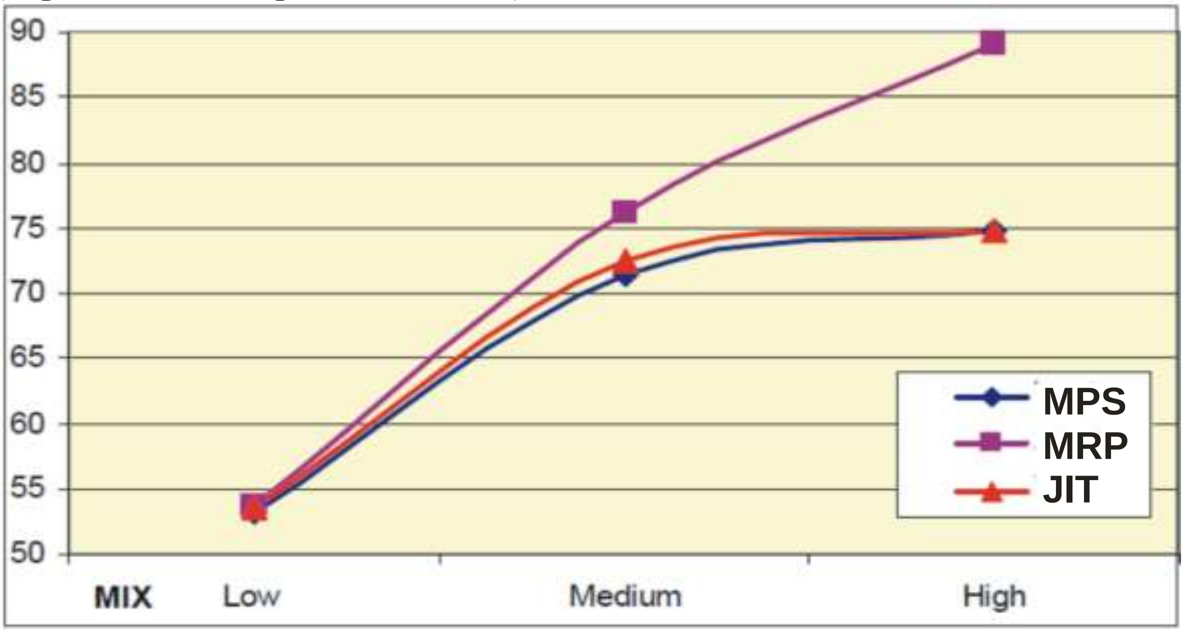
Figure 9: Average Net Operating Income by MAS (High Manufacturing Overhead Level)



4.0 CONCLUSION

The results in the figures above present particularly interesting implications for manufacturing systems. The increase of demand for more complex and higher priced products presents an opportunity for increased revenues. However, it often presents inconsistent results as these products may also drive higher overall manufacturing costs. Higher levels of manufacturing overhead had no significant effect on the product mix decision; however, total costs and differences between the various manufacturing system alternatives are improved. As the manufacturing overhead level setting increases, the slope of the cumulative net operating income curve decreases. The implication for both management and engineers is that the choice of manufacturing system alternative becomes increasingly important as product mix complexity increases and may be amplified as manufacturing overhead levels increase.

As can be seen in the above figures, higher levels of product mix complexity drive increasing long-term variances in cumulative net operating income. Review of manufacturing system performance under the varying experimental conditions (three levels of manufacturing overhead by three levels of product mix complexity) shows no significant difference in cumulative net operating income when product mix complexity is low. Material Resource Planning System (MRP) begins to significantly outperform the other two manufacturing system alternatives at a medium demand setting for product mix complexity. This difference becomes more pronounced as product mix complexity is set at a high level. At this high setting, Just in Time Manufacturing System (JIT) begins to slowly outperform Mass Production System (MPS).

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MODEL.MOD

APPENDIX

```
BEGIN;

! ---------------- Initialisation of buffers -----------------

      CREATE,      3,0:          !Initial Finished parts at Endbuffer
                 :
                 NEXT(Endbuff);
      CREATE,      1,0:          !Initial parts at Buffer2
                 :
                 NEXT(Buff2);

      CREATE,      1,0:          !Initial parts at Buffer1
                 :
                 NEXT(Buff1);

      CREATE,      1,0:
                 :
                 NEXT(Endbuff1);
      CREATE,      1,0:
                 :
                 NEXT(Buff21);
      CREATE,      1,0:
                 :
                 NEXT(Endbuff2);
      CREATE,      1,0:
                 :
                 NEXT(Buff22);
      CREATE,      1,0:
                 :
                 NEXT(Endbuff3);
      CREATE,      1,0:
                 :
                 NEXT(Buff23);
      CREATE,      1,0:
                 :
                 NEXT(Endbuff4);
      CREATE,      1,0:
                 :
                 NEXT(Buff24);

!--------------- Arrivals of orders for items : TVF 113155/R9 ---------------

      CREATE:      UNIF(1440,1584,2):
                 MARK(Arrtime1);
      ASSIGN:      Type=DISC(0.1,1,0.4,2,0.9,3,1.0,4): !Arrival of green Kanbans
                 Priority=1:
                 X(10)=X(10)+1:
                 X(20)=X(20)+Type;

      BRANCH, 1:
                 IF,(X(20).ge.2).and.(X(10).eq.1),Label1:
                 IF,(X(20).ge.10).and.(X(10).ge.2),label1:
                 ELSE,Label2;

Label1     ASSIGN:      X(20)=0;
      DUPLICATE:    1, Board1;        !Send Kanbans to The preceding block

Label2  BRANCH, 1:
                 IF,Type.eq.1,Labela:
                 IF,Type.eq.2,labelb:
                 IF,Type.eq.3,Labelc:
                 ELSE,Labeld;

labela  DUPLICATE:     1,Customer;
        COUNT:        TVF113155_R9_Q30:DISPOSE;
labelb  DUPLICATE:     2,Customer;
        COUNT:        TVF113155_R9_Q60:DISPOSE;
labelc  DUPLICATE:     3,Customer;
        COUNT:        TVF113155_R9_Q90:DISPOSE;
labeld  DUPLICATE:     4,Customer;
        COUNT:        TVF113155_R9_Q120:DISPOSE;
```

```
Customer  QUEUE,       CustomerQ:      !Queues for Kanban cards at Display Board 2
          DETACH;
Endbuff   QUEUE,       EndbufferQ:     !Queues for Finished parts at Endbuffer
          DETACH;
          MATCH:      Customer,Board2:
          Endbuff;

Board2  QUEUE,       Board2Q:      !Queues for Kanban cards at Display Board 2
        DETACH;
Buff2   QUEUE,       Buffer2Q:     !Queues for Finished parts at Endbuffer
        DETACH;
        MATCH:      Board2,Block3:
        Buff2;

! -------------- Arrivals of orders for high-volume items --------------------

    CREATE:      UNIF(2520,3024):
                 MARK(Arrtime2);
    ASSIGN:      Type=DISC(.2,5,.5,6,.75,7,1.0,8):   ! Arrival of High-volume Kanbans
                 Priority=Type;
    BRANCH, 1:
                 IF,Type.eq.5,Labela1:
                 IF,Type.eq.6,labelb1:
                 IF,Type.eq.7,Labelc1:
                 ELSE,Labeld1;

labela1  DUPLICATE:     1, Customer1;
        COUNT:        TVM1137797_R11:DISPOSE;
labelb1  DUPLICATE:     1, Customer2;
        COUNT:        TVM113277_R3:DISPOSE;
labelc1  DUPLICATE:     1, Customer3;
        COUNT:        TVF113666_R24:DISPOSE;
labeld1  DUPLICATE:     1, Customer4;
        COUNT:        TVM1137627_R9:DISPOSE;

! ---- High-volume item 1 ---------

Customer1  QUEUE,       Customer1Q:      !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff1   QUEUE,       Endbuffer1Q:     !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:      Customer1,Board21:
           Endbuff1;

Board21    QUEUE,       Board21Q:      !Queues for Kanban cards at Display Board 2
           DETACH;
Buff21     QUEUE,       Buffer21Q:     !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:      Board21,Block3:
           Buff21;

! ---- High-volume item 2 ---------

Customer2  QUEUE,       Customer2Q:      !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff2   QUEUE,       Endbuffer2Q:     !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:      Customer2,Board22:
           Endbuff2;

Board22    QUEUE,       Board22Q:      !Queues for Kanban cards at Display Board 2
           DETACH;
Buff22     QUEUE,       Buffer22Q:     !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:      Board22,Block3:
           Buff22;
```

```
! ---- High-volume item 3 ---------

Customer3  QUEUE,     Customer3Q:      !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff3   QUEUE,     Endbuffer3Q:     !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:     Customer3,Board23:
           Endbuff3;

Board23    QUEUE,     Board23Q:        !Queues for Kanban cards at Display Board 2
           DETACH;
Buff23     QUEUE,     Buffer23Q:       !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:     Board23,Block3:
           Buff23;

! ---- High-volume item 4 ---------

Customer4  QUEUE,     Customer4Q:      !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff4   QUEUE,     Endbuffer4Q:     !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:     Customer4,Board24:
           Endbuff4;

Board24    QUEUE,     Board24Q:        !Queues for Kanban cards at Display Board 2
           DETACH;
Buff24     QUEUE,     Buffer24Q:       !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:     Board24,Block3:
           Buff24;

! ------------- Arrivals of orders for push-typed items -----------------------

      CREATE:    UNIF(1440,1584,2):
                 MARK(Arrtime3);
      ASSIGN:    Type=DISC(.2,9,.5,10,.8,11,1.0,12): !Arrival of Non-Kanban items
                 Priority=Type;
      BRANCH, 1:
              IF,Type.eq.9,Push_A1:
              IF,Type.eq.10,Push_A2:
              IF,Type.eq.11,Push_A3:
              ELSE,Push_A4;

Push_A1   DUPLICATE:    1, Block1:
          COUNT:      Non_Kanban_Item1:DISPOSE;
Push_A2   DUPLICATE:    1, Block1:
          COUNT:      Non_Kanban_Item2:DISPOSE;
Push_A3   DUPLICATE:    1, Block1:
          COUNT:      Non_Kanban_Item3:DISPOSE;
Push_A4   DUPLICATE:    1, Block1:
          COUNT:      Non_Kanban_Item4:DISPOSE;


! -------------- Production Processes (Block) III -------------------

Block3    QUEUE,      Workstat3Q;     !Start processing at Block 3
          SEIZE:      Workstat3;
        ASSIGN:      OpFactor=BatchF(Type);
        DELAY:       Norm(123,20)*OpFactor;
        RELEASE:     Workstat3;

      BRANCH, 1:
              IF,(Type.ge.5).and.(Type.le.8),CountB3a:
              IF,Type.ge.9,CountB3b:
              ELSE,CountB3c;

CountB3c   DUPLICATE:    1,EndBuff:NEXT(Countr1);
```

```
CountB3a   BRANCH, 1:
              IF,Type.eq.5,Dupl3:
              IF,Type.eq.6,Dupl4:
              IF,Type.eq.7,Dupl5:
              ELSE,Dupl6;

Dupl3   DUPLICATE:   1,EndBuff1:NEXT(Countr2);
Dupl4   DUPLICATE:   1,EndBuff2:NEXT(Countr2);
Dupl5   DUPLICATE:   1,EndBuff3:NEXT(Countr2);
Dupl6   DUPLICATE:   1,EndBuff4:NEXT(Countr2);

Countr1    COUNT:       Total_Prod_TVF113155_R9;
           TALLY:       Flowtime1,Tnow-Arrtime1:DISPOSE;
Countr2    DUPLICATE:   1,Block2;
           COUNT:       Total_Prod_High_Volume;
           TALLY:       Flowtime2,Tnow-Arrtime2:DISPOSE;
CountB3b   COUNT:       Total_Prod_Non_Kanban;
           TALLY:       Flowtime3,Tnow-Arrtime3:DISPOSE;

! -------------- Production Processes (Block) II ---------------------

Board1   QUEUE,     Board1Q:   !Queues for Kanban cards at Display Board 1
         DETACH;
Buff1    QUEUE,     Buffer1Q:  !Queues for materials represent 360 parts
         DETACH;
         MATCH:     Board1,Block2:
         Buff1;

Block2   QUEUE,     Workstat2Q;
         SEIZE:     Workstat2;
         ASSIGN:    OpFactor=TypeF(Type)*BatchF(Type);
         DELAY:     Norm(210.17,90)*OpFactor;
         RELEASE:   Workstat2;

      BRANCH, 1:
              IF,(Type.ge.5).and.(Type.le.8),CountB2a:
              IF,Type.ge.9,CountB2b:
              ELSE,CountB2c;

CountB2c   DUPLICATE:   12,Buff2:NEXT(Counter1);

CountB2a   BRANCH, 1:
              IF,Type.eq.5,Dup33:
              IF,Type.eq.6,Dup44:
              IF,Type.eq.7,Dup55:
              ELSE,Dup66;

Dup33   DUPLICATE:   1,Buff21:NEXT(Counter2);
Dup44   DUPLICATE:   1,Buff22:NEXT(Counter2);
Dup55   DUPLICATE:   1,Buff23:NEXT(Counter2);
Dup66   DUPLICATE:   1,Buff24:NEXT(Counter2);

Counter1   DUPLICATE:   1,Block1;
           COUNT:       OutBlock2_TVF113155_R9:DISPOSE;

Counter2   DUPLICATE:   1,Block1;
      COUNT:      OutBlock2_High_Volume:DISPOSE;

CountB2b   DUPLICATE:   1,Block3;
           COUNT:       OutBlock2_Non_Kanban:DISPOSE;

! -------------- Production Processes (Block) I ---------------------

BLock1   QUEUE,     Workstat1Q;
         SEIZE:     Workstat1;

      BRANCH, 1:
              IF,(Type.le.4),LopF1:
              ELSE,LopF2;
```

```
 LopF1   ASSIGN:     OpFactor=BatchF(Type)*(3000/360):NEXT(Ldelay);
 LopF2   ASSIGN:     OpFactor=BatchF(Type);
 Ldelay  DELAY:      Norm(20,5)*OpFactor;
         RELEASE:    Workstat1;

     BRANCH, 1:
             IF,(Type.ge.5).and.(Type.le.8),CountPa:
             IF,Type.ge.9,CountPb:
             ELSE,CountPc;

CountPc   DUPLICATE:   1,Buff1;
          COUNT:       OutBlock1_TVF113155_R9:DISPOSE;
CountPa   COUNT:       OutBlock1_High_Volume:DISPOSE;
CountPb   DUPLICATE:   1,Block2;
          COUNT:       OutBlock1_Non_Kanban:DISPOSE;

END;
```

MODEL2.EXP

BEGIN;
PROJECT, JIT manufacturing system, Ezema
Chukwuedozie Nnaemeka;

```
ATTRIBUTES:     Arrtime1:
           Arrtime2:
           Arrtime3:
           OpFactor:
           Type:
           Priority;
VARIABLES:      TypeF(12),1.0,1.0,1.0,1.0,1.50,
           1.50,1.00,1.50,1.50,1.50,1.50,
           1.50:
           BatchF(12),1,1,1,1,3.80,6.0,5.0,
           2.0,3.3,3.3,3.3,3.3;
SCHEDULES:      1,1*EXPO(10080),0*720:
           2,1*20160,0*240;
RESOURCES:      Workstat3,SCHED(2):
           Workstat2,SCHED(1):
           Workstat1,SCHED(2);
QUEUES:         CustomerQ:
           EndbufferQ:
           Buffer2Q:
           Buffer1Q:
           Board2Q:
           Board1Q:
           Customer1Q:
           Endbuffer1Q:
           Board21Q:
           Buffer21Q:
           Customer2Q:
           Endbuffer2Q:
           Board22Q:
           Buffer22Q:
           Customer3Q:
           Endbuffer3Q:
           Board23Q:
           Buffer23Q:
           Customer4Q:
           Endbuffer4Q:
           Board24Q:
           Buffer24Q:
           Workstat3Q:
           Workstat2Q:
           Workstat1Q;
COUNTERS:       TVF113155_R9_Q30:
           TVF113155_R9_Q60:
           TVF113155_R9_Q90:
           TVF113155_R9_Q120:
           TVM1137797_R11:
           TVM113277_R3:
           TVF113666_R24:
           TVM1137627_R9:
           Non_Kanban_Item1:
           Non_Kanban_Item2:
           Non_Kanban_Item3:
           Non_Kanban_Item4:
           Total_Prod_TVF113155_R9:
           Total_Prod_High_Volume:
           Total_Prod_Non_Kanban:
           OutBlock2_TVF113155_R9:
           OutBlock2_High_Volume:
           OutBlock2_Non_Kanban:
           OutBlock1_TVF113155_R9:
           OutBlock1_High_Volume:
           OutBlock1_Non_Kanban;
TALLIES:        Flowtime1:
           Flowtime2:
           Flowtime3;

DSTATS:         NQ(CustomerQ):
           NQ(Customer1Q):
           NQ(Customer2Q):
           NQ(Customer3Q):
```

```
            NQ(Customer4Q):
            NQ(EndbufferQ):
            NQ(Endbuffer1Q):
            NQ(Endbuffer2Q):
            NQ(Endbuffer3Q):
            NQ(Endbuffer4Q):
            NQ(Buffer2Q):
            NQ(Buffer21Q):
            NQ(Buffer22Q):
            NQ(Buffer23Q):
            NQ(Buffer24Q):
            NQ(Buffer1Q):
            NQ(Workstat3Q):
            NQ(Workstat2Q):
            NQ(Workstat1Q):
            NR(Workstat3)*100,WS3 Utilisat.:
            NR(Workstat2)*100,WS2 Utilisat.:
            NR(Workstat1)*100,WS1 Utilisat.;
REPLICATE,      10,100,40320;
END;
```

MODEL.OUT

Summary for Replication 1 of 10
Project: JIT manufacturing system **Run execution date :21/ 06/2016**
Analyst: Ezema Chukwuedozie **Model revision date: 21/ 06/2016**

Replication ended at time : 40420.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Flowtime1	375.91	.76476	77.560	1468.7	68
Flowtime2	627.46	.39371	231.96	1199.7	15
Flowtime3	2135.5	.31462	1239.0	3702.0	14

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
NQ(CustomerQ)	.01516	8.0591	.00000	1.0000	.00000
NQ(Customer1Q)	.00000	--	.00000	1.0000	.00000
NQ(Customer2Q)	.00000	--	.00000	1.0000	.00000
NQ(Customer3Q)	.00000	--	.00000	1.0000	.00000
NQ(Customer4Q)	.00000	--	.00000	1.0000	.00000
NQ(EndbufferQ)	2.3812	.43261	.00000	3.0000	3.0000
NQ(Endbuffer1Q)	.95685	.21237	.00000	1.0000	1.0000
NQ(Endbuffer2Q)	.88730	.35640	.00000	1.0000	1.0000
NQ(Endbuffer3Q)	.93669	.25998	.00000	1.0000	1.0000
NQ(Endbuffer4Q)	.98574	.12028	.00000	1.0000	1.0000
NQ(Buffer2Q)	6.0154	.60006	.00000	14.000	5.0000
NQ(Buffer21Q)	.83660	.44194	.00000	1.0000	1.0000
NQ(Buffer22Q)	.58340	.84504	.00000	1.0000	1.0000
NQ(Buffer23Q)	.74884	.57914	.00000	1.0000	.00000
NQ(Buffer24Q)	.89441	.34360	.00000	1.0000	1.0000
NQ(Buffer1Q)	.82898	.45420	.00000	1.0000	1.0000
NQ(Workstat3Q)	.44130	2.0574	.00000	4.0000	.00000
NQ(Workstat2Q)	.54409	1.1588	.00000	2.0000	1.0000
NQ(Workstat1Q)	.00613	12.733	.00000	1.0000	.00000
WS3 Utilisat.	55.690	.89200	.00000	100.00	.00000
WS2 Utilisat.	88.548	.35962	.00000	100.00	100.00
WS1 Utilisat.	8.4997	3.2810	.00000	100.00	.00000

COUNTERS

Identifier	Count	Limit
TVF113155_R9_Q30	4	Infinite
TVF113155_R9_Q60	7	Infinite
TVF113155_R9_Q90	14	Infinite
TVF113155_R9_Q120	2	Infinite
TVM1137797_R11	2	Infinite
TVM113277_R3	6	Infinite
TVF113666_R24	5	Infinite
TVM1137627_R9	2	Infinite
Non_Kanban_Item1	3	Infinite
Non_Kanban_Item2	6	Infinite
Non_Kanban_Item3	3	Infinite
Non_Kanban_Item4	3	Infinite
Total_Prod_TVF113155_R	68	Infinite
Total_Prod_High_Volume	15	Infinite
Total_Prod_Non_Kanban	14	Infinite
OutBlock2_TVF113155_R9	6	Infinite
OutBlock2_High_Volume	14	Infinite
OutBlock2_Non_Kanban	14	Infinite
OutBlock1_TVF113155_R9	6	Infinite
OutBlock1_High_Volume	14	Infinite
OutBlock1_Non_Kanban	15	Infinite