Proceedings of the 1988 Winter Simulation Conference
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Transforming a traditional manufacturing system into a JUST-IN-TIME system with KANBAN

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ABSTRACT

Traditional manufacturing systems, characterized by many U.S. firms, are known for maintaining relatively high levels of raw material, work-in-process, and finished goods inventories as a hedge against uncertainty in supplier delivery and quality, production rates and quality, and customer demand. Just-in-Time (JIT) manufacturing systems, characterized by many Japanese firms, are outperforming their U.S. counterparts by using kanban production control in concert with many other more commonplace operations management techniques. Many U.S. firms have attempted to imitate Japanese methods in piecemeal fashion with limited success perhaps due to a failure to understand JIT as a comprehensive system and philosophy. An excellent means of developing a better understanding of JIT manufacturing and to begin implementing JIT within an existing traditional system is through the use of computer simulation. This paper presents a rationale of JIT and an example of using GPSS/PCtm simulation to study the effects of adopting JIT with kanban production control in an actual U.S. manufacturing environment. This methodology should be applicable to other traditional manufacturing systems desiring to better understand and implement JIT.

1. INTRODUCTION

1.1 U.S. Imitation of Japanese Success

The literature abounds with accounts of how Japanese manufacturing has become the standard of quality and productivity against which U.S. firms compare very unfavorably (Chase and Aquilano 1985, Byrd and Carter 1988, Lubben 1988). Americans often prefer Japanese products on the basis of price and quality. The Japanese have even demonstrated the ability to successfully produce goods in the U.S. with American workers. So influential are the Japanese that many U.S. firms have recently begun to imitate Japanese management techniques (JIT in particular) in the hope of becoming more competitive. However, it may be debated that such imitation is often ineffective because it is not coupled with a more complete understanding of the interaction of all elements of JIT (Myers 1988).

1.2 Simulation and JIT Implementation

Simulation of a traditional manufacturing system with the ability to easily convert the model into a JIT manufacturing system can serve two important purposes: the firm's management can (1) obtain a better understanding of the broad nature of the JIT approach to manufacturing in contrast with their existing traditional manufacturing system and (2) use the simulation model to develop strategy and implement decisions in an attempt to gradually transform their traditional system into a more productive JIT system.

1.3 Overview

This paper first presents a rationale for understanding JIT as an interdependent set of elements which must be properly meshed into a coherent system involving both human and technological aspects. This rationale is essential to understanding the development of the simulation model of an actual manufacturing system presented later. Although the human aspects of the JIT system are not directly included in the model a fair number of the technological aspects are. The model is tested and discussed under a variety of manufacturing conditions relevant to JIT. Finally, the model is run in an effort to determine an acceptable strategy which an existing traditional system could use to improve quality and productivity through the gradual adoption of JIT. Conclusions will then be drawn for the system under investigation and for the applicability of this methodology to other traditional manufacturing systems.

2. RATIONALE FOR JIT MANUFACTURING

2.1 Reasons for Japanese Success

Many have argued that Japanese success in manufacturing is due to cultural differences, to the proximity of Japanese suppliers to the manufacturing plant, or to lifetime employment. Some believe that the Japanese labor rates and/or unfair Japanese importing and exporting practices are primarily responsible for the lower prices of Japanese goods. However, it appears that Japanese success in manufacturing is due in large part to their dedication in using a JIT system

(Chase and Aquilano 1985). U.S. firms are for the most part still committed to the traditional approach characterized by higher defect rates, larger inventory levels, and lower throughput.

2.2 Interplant and Intraplant JIT

The term "just-in-time" is usually taken to apply to either (1) ordering from outside suppliers to support production in such a way as to minimize raw materials inventory, or (2) driving production schedules by customer demand in such a way as to minimize finished goods inventory. These interplant facets of JIT represent only a part of a total JIT manufacturing picture. The bulk of JIT which impacts quality and productivity is concerned with intraplant applications involved in maintaining an optimum work-in-process (WIP) inventory throughout the production process. This intraplant JIT system is usually accomplished by a kanban production control system (JIT-K). This paper focuses only on the intraplant JIT-K application although a very strong set of parallels exist between the interplant and intraplant mechanics of JIT (Lubben 1988).

2.3 Benefits of WIP Inventory Reduction

The most apparent goal of a JIT-K system is to minimize WIP inventory. However, the purpose of reducing WIP inventory is two-fold: (1) reduce carrying costs and (2) improve quality and productivity. While most see the reduction of WIP simply as a means to reduce carrying costs such as interest and storage expense, perhaps the greatest benefit of minimizing WIP is the vastly improved visibility of problems in the manufacturing process, problems which contribute to consistently low quality, high rework, large inventories, and low throughput. Progress toward quality and productivity can only be accomplished when process flaws are exposed and effectively acted upon. By using the JIT-K system the Japanese have the best of both worlds: they expose and correct flaws which first improves quality; improvements in quality result in increased productivity. Reduction in carrying costs can be viewed as an important fringe benefit. Thus, the Japanese produce higher quality at lower cost with the end result being a superior competitive position in world markets.

3. ELEMENTS OF JIT -- APPROACHING THE IDEAL

3.1 The Ideal Manufacturing System

The elements of a JIT-K manufacturing system are quite numerous and must function in a coordinated fashion to be effective as a system (Ebrahimpour and Lee 1987). To understand how JIT-K is designed to operate one can begin by considering the ideal manufacturing system. A multistage, single line process can be viewed as a simple assembly line. If there are no unnecessary delays and no uncertainties present, the system is ideal and productivity will be optimized. It is the presence of uncertainty in each of the many manufacturing system components which amplifies problems and necessitates a JIT approach for solutions (Chapman and Schminke 1988).

3.2 Simplicity, Automation and Methods

Suppose in this ideal factory that the cycle times for each production stage are perfectly balanced and that within each stage there is no variation in cycle time from part to individual part. This goal is approached through a JIT system in a number of different ways. First, improved product design helps to insure manufacturability and provides greater opportunity for automation, thus minimizing variation in cycle time from part to part within a production stage. The average cycle times from stage to stage are balanced through standard industrial engineering practices. It may be surprising to some that product redesign, automation, and classical industrial engineering are considered necessary functions for JIT success. The relative absence of these and other efforts may account for the reason why JIT is not working in some traditional environments.

3.3 Jidoka--Quality at the Source

The ideal factory has virtually perfect quality and reject rates of 0%. The most effective means of approaching this goal is through improved employee involvement. Workers and supervisors are given a much higher degree of responsibility in a JIT system but not without a commensurate amount of training in JIT systems, group problem solving, and a variety of job skills. With such training workers and supervisors can monitor their own production processes and continually check their own quality without the aid of a quality control inspector. When processes do run out of control, operators have the responsibility to shut the process down until the problems are identified and corrected. Formal group problem solving programs enhance both quality and productivity. In fact, such participative management techniques can lead to more motivated workers. The end result of employee involvement in the JIT manufacturing system is higher quality, less rework, and faster throughput, all of which are extremely essential for JIT to operate successfully (Lubben 1988).

3.4 Group Technology

In our ideal JIT system, the process stages are located so close to each other that zero transit time is required when a part is moved between stages. This group technology is approached through improved plant layout and product flow, another industrial engineering function. If transit times are not minimized they simply represent another significant stage in the production sequence decreasing order throughput. Excessive handling and warehousing between production stages in a traditional system can also contribute to quality problems.

3.5 Scheduling, Setup Times, and Lot Sizes

For the ideal JIT system the master schedule is frozen to eliminate unexpected changes in product mix and lost time due to excessive setups. Of course, one way to minimize the detrimental effect of setup times regardless of their frequency is to make a serious effort to reduce them (the Japanese have been successful in reducing setup times from hours to only minutes). Another valuable by-product of reduced setup time is that lot sizes may be significantly reduced without an adverse effect on cost (as demonstrated by the EOQ formula). As lot sizes are reduced the control over quality is enhanced and inventories can be further minimized.

3.6 Preventive Maintenance and SPC

In the ideal system machines virtually never break down. This is because of an excellent preventive maintenance program. Statistical process control (SPC) is used to monitor the most critical aspects of machine performance so that out-of-tolerance conditions can be corrected immediately. The elimination of variation and uncertainty in machine operations vastly improves system performance.

3.7 Kanban Production Control

Even with all the above improvements and safeguards built into the ideal manufacturing system, a kanban production control system should be maintained to effectively restrict the amount of WIP inventory allowed between stages. Kanban production control is the policeman which enforces compliance with stated objectives to identify and solve manufacturing system problems.

In the JIT-K system, units of production are confined to well-defined lots or containers which can be moved from a preceding stage to a succeeding stage only when the succeeding stage is ready to process the lot or when the buffer inventory falls below its allowed number of lots. Equally important in JIT-K is the fact that the preceding stage cannot begin production on a lot until the last lot produced has been removed for processing by the succeeding stage. The total number of lots allowed in a production stage at any one time is called the number of kanbans and is usually kept to a minimum of one or two in a JIT-K system. It is when the buffer inventory preceding a stage is allowed to grow virtually without limit that a system can be described as traditional. The original Toyota kanban system (kanban is Japanese for "card" or "visible record") used a fixed number of cards to accompany lots throughout production. The kanbans provide the only authority to move lots from stage to stage and thus limit WIP inventory. This type of hand-to-mouth feeding from stage to stage prevents excessive WIP inventories from building which forces production to keep quality under control while reducing carrying costs.

4. THE TRADITIONAL SYSTEM UNDER INVESTIGATION

A particular factory was selected to serve as an example of using simulation to investigate the application of JIT principles to an existing traditional system. This factory produces molded plastic parts in a multistage, single line process which consists of four stages: (1) Molding, (2) Painting, (3) Foiling, and (4) Packaging. Large inventories of parts are maintained after each production process in order to keep each production stage running at maximum utilization. Quality Control inspectors are used to spot check the Molding and Painting operations while 100% inspection occurs after the Foiling operation. Rework operators are utilized following Stage 3 to repair the defective units. The process times in each stage are not balanced requiring large buffer inventories to maintain production. A high degree of variability in product design from part number to part number often results in poor manufacturability and high defect rates. The greatest problem in production is seen as the malfunction or breakdown of equipment. Production schedules are prone to change very frequently due to changing marketing requirements and equipment breakdown. Setup times usually run several hours. The production departments are located very close to each other but the warehousing of buffer stock (and raw materials) is relatively remote. Methods work and time study to improve setup and process times is limited since most of the engineers' time is spent solving process problems.

In order for such a traditional system to begin implementing JIT several basic steps should be considered. Quality inspection should be performed within each stage by machine operators. Process cycle times from stage to stage should be better balanced and cycle time variation within a stage should be minimized through methods study, automation, etc. Product redesign, setup time reduction, preventive maintenance, employee participation, and SPC can be developed within a kanban production control system to restrict WIP inventory. Simulation of the system can help guide management along the proper JIT course.

5. THE SIMULATION MODEL

5.1 General Aspects of the Model

Kanban Production Control. The simulation model represents a simplified version of the manufacturing system described above. Orders for plastic cabinets arrive with frequency and size controlled by the analyst. Since this paper is not concerned with interplant JIT supplier networks, the arrival of orders is adjusted so that the plant never runs out of work. Raw materials are assumed to be always available. When a new order arrives at stage 1 (Molding) it is processed in a series of lots the size of which can be controlled by the analyst. The number of lots which can be accumulated prior to stages 2, 3, and 4

(Paint, Foil, and Package, respectively) can also be controlled by the analyst. If the number of lots allowed at each stage is only one, then a completed lot cannot move to a succeeding stage until the succeeding stage is ready for production. If the number of lots allowed at each stage is two then two lots can exist in a stage simultaneously (one being processed and one as a buffer). This number of lots allowed thus becomes the number of kanbans of a Japanese JIT-K system. If the number of lots (kanbans) allowed are increased, the system eventually becomes a traditional one with each stage maintaining large buffers as required depending on line balance, variation in processing time, setup time, transit time, etc.

Cycle Tme. Orders for cabinets enter the system and lots from these orders move from stage to stage. The amount of processing time required for each lot at each stage is determined by the analyst. The variation in processing time can be controlled most simply by a uniform distribution about the mean. The mean processing times for each stage can be changed to reflect balanced or imbalanced conditions.

Transit Time. The time required to move a completed lot of parts from one stage to the next can be controlled by the analyst.

Setup Time. The frequency of new orders entering the factory and moving through the various stages of production can be controlled directly in the model by adjusting the rate of arrival and/or the size of the order. Either will affect the frequency of setups required in each stage. The setup time in each stage can be changed to determine relationships between lot sizes and number of kanbans for optimum operating conditions.

Defect Rates. The defect rates encountered during Stage 3 (Foiling) in the model can be adjusted to determine the impact on operating a JIT-K system. In this system, the defective units must be repaired by rework operators and reprocessd by the same machines. This is accomplished in the model by rerouting the reworked unit back through the same assembly line.

Model Output. The performance of the modeled system can be evaluated y observing the output in three areas: (1) the total number of cabinets produced over a iven period of time, (2) the total WIP inventory required to maintain that level of production and (3) the average makespan (time required to completely produce an order) over a given period of time.

Although the model simulates the logical process of the real system and includes the mechanism to control production with any number of kanbans, it provides for only one total production line (one molding machine, one painting assembly line, one foiling assembly line, and one Packaging assembly line). In reality, there are as many as ten to twenty such machines/lines in each stage operating simultaneously. This fact implies that the model output in the areas of WIP inventory and quantity produced should be factored accordingly to be representative of the real system. For example, a WIP figure of 1000 units resulting from a model-run could represen an actual WIP of perhaps 10,000 to 20,000 units).

5.2 Specific Aspects of the Model

Modeling Kanbans. The model was developed using GPSS/PC on an IBM AT compatible microcomputer. Some of the key elements in developing the model are the use of the STORAGE command and the accompanying ENTER/LEAVE model blocks to control the number of kanbans in the JIT-K system. Through the appropriate use of ENTER and LEAVE blocks, a lot transaction is not allowed to leave a production stage until the succeeding stage is able to accept it. QUEUE and DEPART block are used to gather data on the amount of WIP inventory accumulated prior to each production stage. The SPLIT block is used to generate lot transactions from the parent order transaction until the order quantity is depleted. Then the ASSEMBLE block is used to collect the separate lot transactions so that order makespan can be determined. The value of this type of model is that it can be used for either JIT-K or traditional systems by simply altering the number of kanbans (STORAGE units) used at each stage of production. See Schriber (1974) for a detailed explanation of the GPSS simulation language. A partial program listing for this model is provided in the appendix.

Methodology. The methodology employed is to verify and validate the model according to the way in which the factory is presently running while including the kanban mechanism so that the present system (with relatively unlimited WIP storage capacity) can be transformed into a JIT-K system. The impact which reducing the number of kanbans has on the system can thus be studied under the present environment of defect rates, setup times, transit times, line balance, cycle time variaton, schedule stability, etc. An optimum number of kanbans to be used in the production control system can be determined based on the present state of the system. As improvements are made in the various production parameters the model parameters can be changed and the model rerun to determine a revised strategy for kanban production control and optimum performance. It is through this process that a traditional system can be gradually transformed into a JIT system The cost effectiveness of implementing changes in the manufacturing system can also be studied using the simulation model. For example the impact which spending $500,000 on automation will have on cycle times, cycle time variation, WIP inventory, output, quality and makespan can easily be estimated using the simulation model within the context of a JIT-K system BEFORE the money is spent.

6. EXPERIMENTATION

6.1 Experimental Design

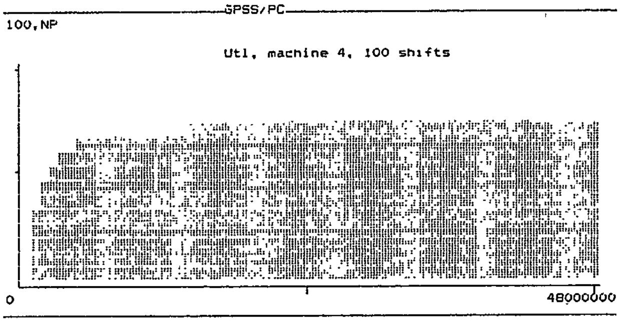
The following parameters are considered input variables to the model:

(a) mean cycle time per unit per stage
(b) cycle time variation per unit as a +/- percentage of the mean (uniform distribution),
(c) reject percentage of a lot (stage 3 only),
(d) downtime rate and times of machines in each stage,
(e) setup time required at each stage,
(f) transit time required at each stage,
(g) the number of kanbans (buffer lots <u>including</u> the lot in process) allowed at each stage

Model output for the following variables are recorded for each model run:

(a) the total number of units produced during the time period specified in the model,
(b) the total WIP inventory carried (excluding the lot which is being actively processed),
(c) the order makespan (average time o produce a lot from beginning to end),
(d) the average machine utilization for all four stages of production.

For each model-run the system is allowed to achieve steady state before statistics are gathered on system performance. This is accomplished by clearing the system and running the model for 40 shifts. This amount of time is determined by observing the utilization of the last machine in the process with the aid of the PLOT command in GPSS/PC (Figure 1). The model is then reset before the actual model-run. A series of five replications of 100 shifts each are then performed for each individual experiment with the results averaged and summarized in the tables which follow.



Simulation Complete

Figure 1: Plot of utilization of machine 4 for 100 shifts.

For the first set of experiments, each of the input variables is examined individually as a dependent variable with the number of kanbans as the indeendent variable to determine the effect of JIT-K on system performance. For the second set of experiments, all the parameters of the manufacturing system are included simultaneously in the model to determine the effect JIT-K has on a complete system. These input parameters are changed to simulate the effect of improvements made in the real system (rejects, downtime, etc.) within the context of JIT-K.

6.2 Experiment Results--Univariate Approach

<u>The Ideal System</u>. A model-run is first performed for the ideal system. Various numbers of kanbans are tested when there is no imbalance in cycle times from stage to stage, no cycle time variation, no rejects, no downtime, no setup time, and no transit time. The results are shown in Table 1. As expected, a total of 480 units per shift are produced for any number of kanbans since there are no delays in this ideal system. Zero WIP (buffer) inventory is accumulated and the makespan for each order is 21.6 hours with no variation. The following experiments are now performed representing a deviation from the ideal system one variable at a time.

Table 1: The Ideal System

INPUT PARAMETERS:		Cycle Times (minutes)	Part #1	Part #2	Part #3	Part #4
Order Size =	1000 units					
Lot Size =	100 units	Stage 1 =	1.00	***	***	***
Setup Time =	0 min	Stage 2 =	1.00	***	***	***
Transit Time =	0 min	Stage 3 =	1.00	***	***	***
Reject Rate =	0 %	Stage 4 =	1.00	***	***	***
Downtime Rate =	0 %	Cycle Var =	+/- 0% (uniform distribution)			

OUTPUT PARAMETERS:	Kanbans /Stage	Average WIP (units)	Makespan (hours)	Output /Shift (units)	Avg. Utl. (%)
	1	0	21.6	480	100
	2	0	21.6	480	100
	3	0	21.6	480	100
	4	0	21.6	480	100
	5	0	21.6	480	100
	10	0	21.6	480	100

<u>Cycle-Time Variation</u>. Tables 2a and 2b illustrate the effects of a +/- 10% and a +/- 20% (uniform) variation in cycle time (the mean cycle time is perfectly balanced at 1.0 minutes per unit in all four stages). In both cases, the one-kanban system results in less output than the two-kanban system. The two-kanban system performs better in WIP and makespan with approximately equal output compared to the three-plus kanban systems. The choice between higher output or higher WIP depends on costs to produce the extra product (such as overtime) and costs to warehouse the extra product (such as interest and storage expense).

Table 2a: Cycle Time Variation (+/- 10%)

INPUT PARAMETERS:		Cycle Times (minutes)	Part #1	Part #2	Part #3	Part #4
Order Size =	1000 units					
Lot Size =	100 units	Stage 1 =	1.00	***	***	***
Setup Time =	0 min	Stage 2 =	1.00	***	***	***
Transit Time =	0 min	Stage 3 =	1.00	***	***	***
Reject Rate =	0 %	Stage 4 =	1.00	***	***	***
Downtime Rate =	0 %	Cycle Var =	+/- 10% (uniform distribution)			

OUTPUT PARAMETERS:	Kanbans /Stage	Average WIP (units)	Makespan (hours)	Output /Shift (units)	Avg. Utl. (%)
	1	111	22.6	455	95
	2	337	24.8	477	100
	3	304	25.0	477	100
	4	370	26.2	477	100
	5	305	24.9	479	100
	10	361	25.9	477	100

Table 2b: Cycle Time Variation (+/- 20%)

```
INPUT PARAMETERS:            Cycle Times (minutes)
Order Size =    1000 units              Part #1 Part #2 Part #3 Part #4
Lot Size =       100 units  Stage 1 =   1.00    ***     ***     ***
Setup Time =       0 min    Stage 2 =   1.00    ***     ***     ***
Transit Time =     0 min    Stage 3 =   1.00    ***     ***     ***
Reject Rate =      0 %      Stage 4 =   1.00    ***     ***     ***
Downtime Rate =    0 %     Cycle Var   +/- 20% (uniform distribution)

OUTPUT PARAMETERS:     Kanbans Average Makespan Output          Avg. Utl.
                       /Stage    WIP   (hours)  /Shift             (%)
                               (units)          (units)
                           1      123     23.5     435              91
                           2      247     24.3     470              99
                           3      395     26.7     479              99
                           4      557     29.3     477              99
                           5      573     29.5     474             100
                          10      594     29.9     476             100
-------------------------------------------------------------------------
```

Stage Cycle Imbalance. Table 3 shows the results of using imbalanced cycle times (the average of which is still 1.0 minutes per unit). There is of course a marked reduction in overall output. Notice however that increasing the number of kanbans does not increase output but does increase makespan and WIP inventory.

Table 3: Stage Cycle Imbalance

```
INPUT PARAMETERS:            Cycle Times (minutes)
Order Size =    1000 units              Part #1 Part #2 Part #3 Part #4
Lot Size =       100 units  Stage 1 =   1.00    ***     ***     ***
Setup Time =       0 min    Stage 2 =   1.50    ***     ***     ***
Transit Time =     0 min    Stage 3 =   1.00    ***     ***     ***
Reject Rate =      0 %      Stage 4 =   0.50    ***     ***     ***
Downtime Rate =    0 %     Cycle Var   +/-  0% (uniform distribution)

OUTPUT PARAMETERS:     Kanbans Average Makespan Output          Avg. Utl.
                       /Stage    WIP   (hours)  /Shift             (%)
                               (units)          (units)
                           1      133     30.0     320              67
                           2      233     32.5     320              67
                           3      333     35.0     320              67
                           4      433     37.5     320              67
                           5      533     40.0     320              67
                          10     1033     50.0     320              67
-------------------------------------------------------------------------
```

Reject Rates. For this particular manufacturing system, defectives are identified only after Stage 3 (Foiling) is completed. Unique to this system is the fact that repairs to these defectives usually require the same series of machines which are already set up for the regular production process. This means that the defectives are usually rerouted immediately down the same production line used for virgin product resulting in what can at times be a serious bottleneck.

Table 4 shows that for a reject rate of 10%, output is maximized first for a total of three kanbans (a maximum of two lots waiting plus one lot in process). However, the WIP and makespan are higher for the three-kanban system than the two-kanban system. There would be an obvious disadvantage of utilizing a traditional system (more than three kanbans) at this reject rate.

Table 4: Rejects at Stage 3

```
INPUT PARAMETERS:            Cycle Times (minutes)
Order Size =    1000 units              Part #1 Part #2 Part #3 Part #4
Lot Size =       100 units  Stage 1 =   1.00    ***     ***     ***
Setup Time =       0 min    Stage 2 =   1.00    ***     ***     ***
Transit Time =     0 min    Stage 3 =   1.00    ***     ***     ***
Reject Rate =     10 %      Stage 4 =   1.00    ***     ***     ***
Downtime Rate =    0 %     Cycle Var   +/-  0% (uniform distribution)

OUTPUT PARAMETERS:     Kanbans Average Makespan Output          Avg. Utl.
                       /Stage    WIP   (hours)  /Shift             (%)
                               (units)          (units)
                           1      257     30.1     320              69
                           2      402     27.3     438              93
                           3      602     31.0     463              93
                           4      802     34.6     463              93
                           5     1002     38.3     463              93
                          10     1982     56.0     463              93
-------------------------------------------------------------------------
```

Setup Time. Table 5 gives the results of requiring a setup time of 30 minutes for each of the four production stages whenever a lot having a new part number arrives. The two-kanban system yields higher output with slightly higher WIP and identical makespan when compared with the one-kanban system. There would be no advantage in using more than two kanbans per stage.

Table 5: Setup Time

```
INPUT PARAMETERS:            Cycle Times (minutes)
Order Size =    1000 units              Part #1 Part #2 Part #3 Part #4
Lot Size =       100 units  Stage 1 =   1.00    1.00    1.00    1.00
Setup Time =      30 min    Stage 2 =   1.00    1.00    1.00    1.00
Transit Time =     0 min    Stage 3 =   1.00    1.00    1.00    1.00
Reject Rate =      0 %      Stage 4 =   1.00    1.00    1.00    1.00
Downtime Rate =    0 %     Cycle Var   +/-  0% (uniform distribution)

OUTPUT PARAMETERS:     Kanbans Average Makespan Output          Avg. Utl.
                       /Stage    WIP   (hours)  /Shift             (%)
                               (units)          (units)
                           1      116     23.6     430              92
                           2      178     23.6     468             100
                           3      178     23.6     468             100
                           4      178     23.6     468             100
                           5      178     23.6     468             100
                          10      178     23.6     468             100
-------------------------------------------------------------------------
```

Downtime. The effects of 10% downtime on the system are somewhat devastating. However, Table 6 demonstrates that varying the number of kanbans has virtually no effect on output, makespan or WIP inventory.

Table 6: Downtime

```
INPUT PARAMETERS:            Cycle Times (minutes)
Order Size =    1000 units              Part #1 Part #2 Part #3 Part #4
Lot Size =       100 units  Stage 1 =   1.00    ***     ***     ***
Setup Time =       0 min    Stage 2 =   1.00    ***     ***     ***
Transit Time =     0 min    Stage 3 =   1.00    ***     ***     ***
Reject Rate =      0 %      Stage 4 =   1.00    ***     ***     ***
Downtime Rate =   10 %     Cycle Var   +/-  0% (uniform distribution)

OUTPUT PARAMETERS:     Kanbans Average Makespan Output          Avg. Utl.
                       /Stage    WIP   (hours)  /Shift             (%)
                               (units)          (units)
                           1      112     32.5     305              83
                           2      126     31.6     323              87
                           3      117     32.0     314              87
                           4      133     32.0     322              87
                           5      119     32.2     316              86
                          10      135     32.0     322              89
-------------------------------------------------------------------------
```

6.3 Experiment Results--Multivariate Approach

Worst Case. The model is run with all input parameters coming into play simultaneously to determine the effect which JIT-K has as the number of kanbans is increased. In this worst case, the stages are severely imbalanced, cycle time variation is +/- 20%, reject rates are 20%, downtime is 10%, setup is 60 minutes for each stage, and transit time is 10 minutes for each stage. As Table 7 indicates, the output remains fairly constant from two kanbans to ten kanbans but WIP and makespan increases dramatically. The total output is only about half of the output from the ideal system. Using two kanbans should be a better alternative since output is constant while WIP is minimized. The totally traditional approach (unlimited kanbans) seems out of the question.

Table 7: Worst Case Combination

INPUT PARAMETERS:		Cycle Times (minutes)				
Order Size =	1000 units		Part #1	Part #2	Part #3	Part #4
Lot Size =	100 units	Stage 1 =	1.00	1.50	0.50	1.00
Setup Time =	60 min	Stage 2 =	1.50	1.00	1.00	0.50
Transit Time =	10 min	Stage 3 =	0.50	1.00	1.50	1.00
Reject Rate =	20 %	Stage 4 =	1.00	0.50	1.00	1.50
Downtime Rate =	10 %	Cycle Var	+/- 20% (uniform distribution)			

OUTPUT PARAMETERS:	Kanbans /Stage	Average WIP (units)	Makespan (hours)	Output /Shift (units)	Avg. Utl. (%)
	1	233	48.8	207	65
	2	341	44.4	252	78
	3	516	49.7	239	79
	4	804	61.2	233	75
	5	1001	69.5	246	73
	10	1959	96.2	258	76

Improved Case. Table 8 gives the results of making a 50% improvement in all input parameters. Output is up slightly compared with Table 7 while makespan and WIP are fairly equivalent. Again, using a two- or three-kanban production control system would appear advantageous compared with a traditional system.

Table 8: Improved Case

INPUT PARAMETERS:		Cycle Times (minutes)				
Order Size =	1000 units		Part #1	Part #2	Part #3	Part #4
Lot Size =	100 units	Stage 1 =	1.00	1.25	0.75	1.00
Setup Time =	30 min	Stage 2 =	1.25	1.00	1.00	0.75
Transit Time =	5 min	Stage 3 =	0.75	1.00	1.25	1.00
Reject Rate =	10 %	Stage 4 =	1.00	0.75	1.00	1.25
Downtime Rate =	5 %	Cycle Var	+/- 10% (uniform distribution)			

OUTPUT PARAMETERS:	Kanbans /Stage	Average WIP (units)	Makespan (hours)	Output /Shift (units)	Avg. Utl. (%)
	1	233	46.6	215	66
	2	404	45.4	257	79
	3	590	50.1	262	80
	4	800	56.0	266	81
	5	1003	63.7	257	79
	10	1995	92.4	265	81

Much-Improved Case. Table 9 shows the results of making another 50% improvement in input parameters. Overall, there appears to be a slight improvement in output while WIP and makespan remaining about the same. Again, operating with two or three kanbans appears advantageous to the traditional approach.

Table 9: Much-Improved Case

INPUT PARAMETERS:		Cycle Times (minutes)				
Order Size =	1000 units		Part #1	Part #2	Part #3	Part #4
Lot Size =	100 units	Stage 1 =	1.000	1.125	0.875	1.000
Setup Time =	15 min	Stage 2 =	1.125	1.000	1.000	0.875
Transit Time =	2.5 min	Stage 3 =	0.875	1.000	1.125	1.000
Reject Rate =	5 %	Stage 4 =	1.000	0.875	1.000	1.125
Downtime Rate =	2.5 %	Cycle Var	+/- 5% (uniform distribution)			

OUTPUT PARAMETERS:	Kanbans /Stage	Average WIP (units)	Makespan (hours)	Output /Shift (units)	Avg. Utl. (%)
	1	244	47.2	215	66
	2	400	46.0	265	81
	3	596	50.2	273	83
	4	799	58.6	270	82
	5	1003	63.1	267	81
	10	1996	89.7	271	83

6.4 Suggestions for Further Study

While the model used for this study was representative of an actual manufacturing system it did not include all the machines and lines found in the real system. A model could be developed for this factory (or any other) to include all relevant facilities. Then the model could more accurately predict output in an absolute sense. The model could also be enhanced by using a gamma distribution (instead of the uniform distribution) to model processing cycle times (Law and Kelton 1982).

While interplant JIT functions were not included in this model, the addition of such would give a more complete picture of the overall process of JIT implementation. JIT applied to purchasing, receiving, and delivery can have a pronounced impact on raw materials and finished goods inventories as well as WIP.

As more detailed models are developed of actual unique manufacturing environments, a more rigorous statistical treatment of the results should be applied in order to increase confidence in the decision-making process relative to actual JIT-K implementation.

7. CONCLUSIONS

This simulation model does illustrate the delicate interrelationships between the large number of elements involved in either a traditional or JIT-K manufacturing system. The development of detailed models for unique manufacturing systems should assist managers in understanding their existing system and in determining strategies for improving performance even if JIT-K is not being considered.

The effect which a JIT-K production control system can have on several manufacturing system elements taken individually can be easily demonstrated using a simulation model of the unique factory. The process of simulating the effect of JIT-K on an existing system one variable at a time should assist managers and engineers in developing a more comprehensive understanding of the requirements for a successful JIT-K system. Using simulation, management can decide which elements of their existing system (rejects, downtime, setup, cycle imbalance, cycle variation) currently have the greatest negative impact on productivity in either a traditional or JIT-K environment. Corrective action can then be better focused.

Finally, all critical parameters of an existing system can be included in a simulation model and tested under a JIT-K production control system. The results for this set of experiments again show that a JIT-K system yields about the same output as the traditional system but with significant reductions in WIP and makespan. With the aid of simulation managers can estimate how performance can be affected as different strategies are employed for improvements within the context of JIT-K. The cost effectiveness of these strategies can thus be ascertained for each unique manufacturing system.

APPENDIX: PARTIAL PROGRAM LISTING

Following is a partial listing of the GPSS/PC model program showing the logic of lot transaction flow in stage 2 of production:

```
                         GPSS/PC
FACTORY STORAGE       1
STAGE1  STORAGE       1                    ;max # of xact's allowed in STAG
STAGE2  STORAGE       10
STAGE3  STORAGE       10
STAGE4  STORAGE       10
*
LOTSIZE EQU           100                  ;number of units in each lot
*
SHIFT   EQU           480000               ;shift duration is 480 minutes
ORDERARR EQU          SHIFT                ;order interarrival time
HWPCT   EQU           5                    ;half width percentage for cycle
*
ORDERQTY EQU          1000                 ;order size as a constant
ORDERQTY FUNCTION     RN1,D5               ;order size as a function
/.5,500/.8,1000/.9,1500/1,2000
*
PARTNO4 FUNCTION      RN1,D5               ;four different part nos.
/.25,1/.5,2/.75,3/1,4
```

```
                   Simulation Complete
                         GPSS/PC

QUE2    QUEUE        QUEUE2                ;lot enters queue for stage 2
        ENTER        STAGE2                ;lot attempts to enter stage 2
        LEAVE        STAGE1                ;lot leaves, makes room for next
        SEIZE        MACH12                ;lot seizes machine #1 in stage
        DEPART       QUEUE2                ;when processed, lots leaves que
        TEST NE      P$ORDNUM,X$PREVORD2,SAVE2 ;test for setup on new P/N
        ADVANCE      SETUP2                ;setup time for stage 2
SAVE2   SAVEVALUE    PREVORD2,P$ORDNUM     ;save lot order # in PREVORD2
        ADVANCE      V$TIME2,V$HALFWIDTH2 ;lot processing time
        ADVANCE      V$DT2                 ;machine downtime (if any)
        SAVEVALUE    COMPQTY2+,P$REMQTY    ;accum prod. qty in COMPQTY2
        RELEASE      MACH12                ;lot releases machine
        ADVANCE      TRANSIT3              ;lot transit time to next stage
*
QUE3    QUEUE        QUEUE3
        ENTER        STAGE3
        LEAVE        STAGE2
        SEIZE        MACH13
```

DISCLAIMER

IBM AT is a product of the IBM Corporation. GPSS/PC is a trademark of Minuteman Software.

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