Designing prototypes of JIT systems using system dynamics principles

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Abstract. American and European firms use just in time prototypes which are subsets of the japanese just in time system. Hence, these firms need tools to select those components of the japanese JIT system best suited to their particular characteristics and environments. This paper proposes one of such tools and illustrates its application on a case study. The proposed tool is a computer aided procedure that implements system dynamics principles using a continuous-discrete simulation language.

1. Introduction.

The japanese just in time (JIT) manufacturing system consists in most of the changes shown in table 1. A just in time prototype (JITP) is a subset of the japanese JIT system (Shingo, 1981). The JITP includes those JIT components best suited to the particular characteristics of the firm and its environment. Empirical surveys (Gilbert, 1990; Voss, 1987) and detailed case studies (Voss, 1990; Piper, 1990; Celley, 1986) show that American and European firms implement JITPs rather than JITs.

Current tools to design JITPs include detailed checklists (Bartezzaghi, 1989) and cause-effect diagrams (Mizuno, 1988; Fukuda, 1989). However, these tools do not capture the dynamics due to the interactions of the system components. These interactions can be generated by feedbacks that are difficult to detect and can be missed by the managers (Sterman, 1989).

In section two of this paper, a computer aided procedure that overcomes these shortcomings is presented. In section three, this procedure is applied to design a JIT prototype on a case study.

2. A computer aided procedure to design JIT prototypes

Figure 1 shows the proposed procedure to design a JITP. This procedure is a computer aided learning process that focuses the current behavior of the manufacturing system on the

Table 1. Current successful changes in the organization of a manufacturing system. Most of these changes are elements of the J.I.T. system

Nature of the change	Reference for the detailed design of the change
1) Product and manufacturing process analysis	
1.1 Product value analysis and simplification	SUZUE T. (1990)
1.2 Simultaneous engeneering design of the product	SUZUE T. (1990)
2) Flow manufacturing	
2.1 Group technology and parts commonality	BURBIDGE J.L. (1975)
2.2 Manufacturing cells	MONDEN Y. (1983)
2.3 Assembly line organization	HARMON R. (1990)
2.4 Small lot transportation and space denial	HARMON R. (1990)
2.5 Focused storage	HARMON R. (1990)
2.6 Automation with a human touch	HIRANO R. (1988)
2.7 Small in line movable machines	HIRANO R. (1988)
2.8 In house equipement and site technology	KOBAYACHI I. (1990)
3) Operations analysis	
3.1 Set-up time reduction	SHINGO S. (1985)
3.2 Standard operations and value added motions	J. M. A. (1990)
4) Human factors	
4.1 Principles of orderliness and cleanliness	SUGIYAMA Y. (1989)
4.2 Multiprocess handling and multiskilled operators	MONDEN Y. (1983)
4.3 Mutual line assitance	HIRANO H. (1988)
4.4 Efficiency control using standard times	KOBAYACHI I. (1990)
4.5 Zero defect quality control system	SHINGO S. (1986)
4.6 Employee involvement in continuous problem solving	J.H.R.A (1988)
4.7 Total productive maintenance	NAKAJIMA S. (1989)
4.8 Visual control and signal boards	HIRANO H. (1990)
4.9 Focused plant human organisation	HARMON R. (1990)
5) Production planning and information flows	
5.1 Fractionned lots production planning	WANTUCK K. (1989)
5.2 Mixed lots production planning	SUZAKI K. (1987)
5.3 Synchronised scheduling and cycle control	WANTUCK K. (1989)
5.4 Undercapacity scheduling	SHINGO S. (1981)
5.5 Pull-Kanban production planning	MONDEN Y. (1983)
5.6 Push-M.R.P. production planning	FOGARTY D. (1983)
5.7 Shop floor planning control	GROOVER M. (1984)
5.8 Developping the suppliers	SUZAKI K. (1987)
5.9 Permanent materials kit and standardised containers	HARMON R. (1990)
6) Automation	
6.1 Computer aided design	GROOVER M. (1984)
6.2 Numerical control machines and computer aided manufacturing	GROOVER M. (1984)
6.3 Robotics technology	GROOVER M. (1984)
6.4 Automated material handling	GROOVER M. (1984)
6.5 Computer process control and automated testing	GROOVER M. (1984)
6.6 Automated assembly systems	GROOVER M. (1984)

desired one. The convergence towards the desired behavior is obtained by the progressive agreement of the suggestion team and the approval committee. The suggestion team is formed by the individuals related to the sources of the current behavior of the system. The approval committee includes all the managers that possess the necessary background for accepting or rejecting the proposals of the suggestion team. These two groups work independently but they have at least one common member in order to ensure that the suggestions are in accordance with the objectives of the approval committee.

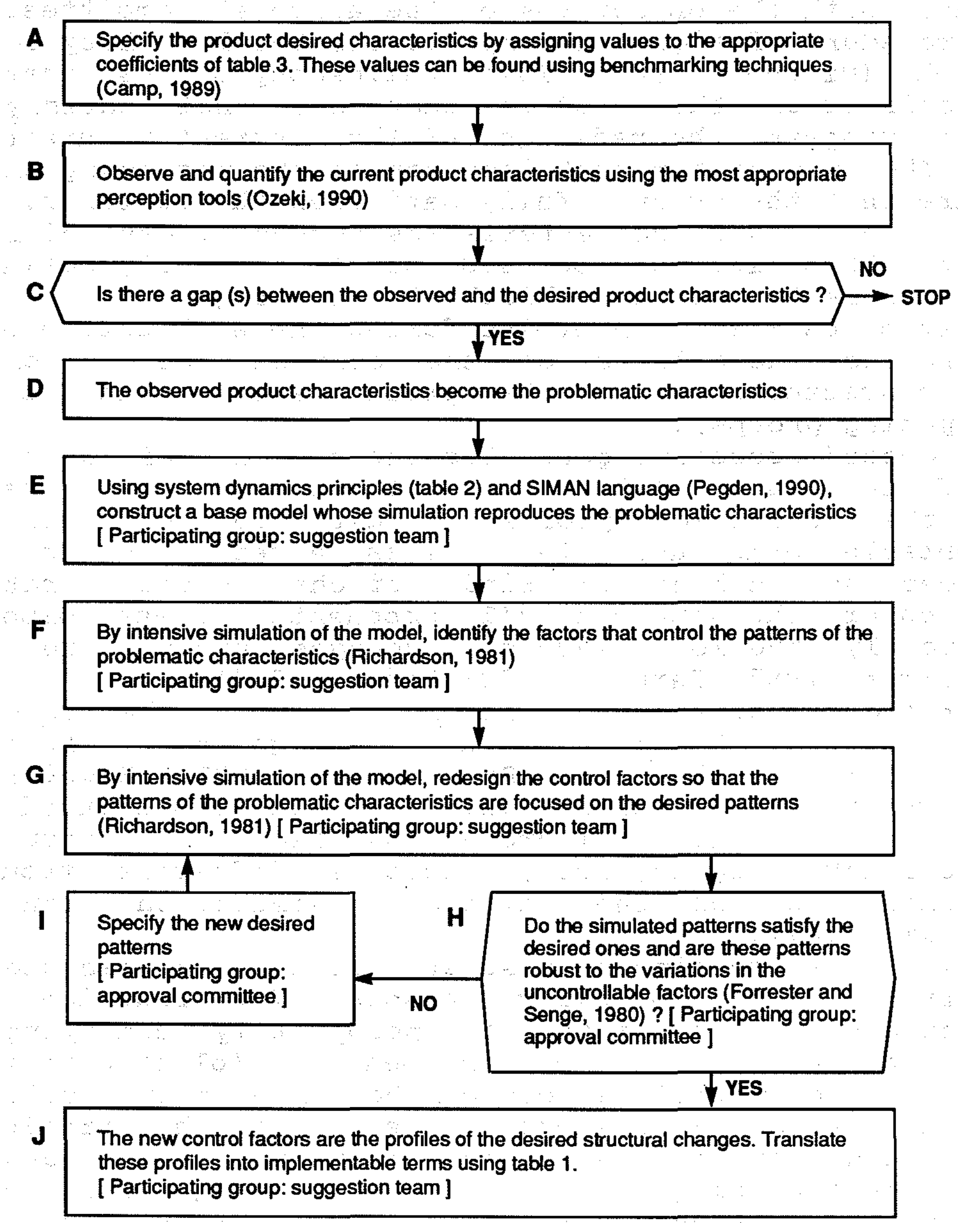
The procedure of figure 1 respects the total quality control philosophy (Mizuno, 1989). This philosophy states that any characteristic of the product that does not satisfy the customer triggers the redesign of the current manufacturing system. The new system must incorporate the necessary changes to ensure that the product fully satisfies the customer. Table 3 shows the product characteristics currently desired by the customers. This list must be used only to initially define the desired characteristics (block A in figure 1). These characteristics will then evolve during the application of the procedure (as the effects of the control factors on the current characteristics of the product are learned by the participating groups).

The proposed procedure generates the profiles of the changes (block J in figure 1) but does not specify their nature. Hence, the obtained profiles must be converted to implementable terms using table 1 as a reference list. This table does not include all kinds of changes and is rather a collection of the japanese JIT components. These components are currently the most succesful changes around the world (Schonberger, 1987; Harmon, 1990; Hayes, 1984).

The procedure of figure 1 is inspired on the reference approach (Macedo, 1990), a strategy design method based on system dynamics methodology (Richardson, 1981). However, the system dynamics principles (table 2) are implemented here using the continuous-discrete manufacturing simulation language SIMAN (Pegden, 1990). This is different from the traditional use of the discrete simulation languages (Krajewski, 1987).

The use of a continuous-discrete simulation language is necessary for the following reasons. The redesign of a problematic system consists of appropiately modifying the factors that control its current behavior (block G in figure 1). When these control factors can be captured by modelling a few of the most significant patterns of the problematic system, the differential equations are useful (these equations are then solved using any continuous language, for example DYNAMO or the continuous features of SIMAN). However, when these control factors belong to the internal organization (arrangement) of the system components they are not easily modelled with the differential equations (Simon, 1969). In this case, any discrete language (for example, the discrete features of SIMAN) must be used. Notice, however, that most of

Figure 1. Procedure to redesign a manufacturing system so that it generates a product that satisfies some desired characteristics. The decisions of the individuals in the participating groups are aggregated using the nominal group technique.



the control factors related to the design of a JIT prototype belong to the organization of the manufacturing system components (table 1).

3. A case study

In this section the proposed procedure is used to design a just in time protoype on a case study. The relevant results are the following ones.

When the time between the arrival orders to an assembly line is 5 days, the product characteristics desired by the customer are respected: high quality (all the assembled products show zero defects), relatively low cost (because the stock of parts waiting to be assembled oscillates between zero and one products) and low delivery delay (between 2 and 4 days). As a consequence, the customer order size is very good, it oscillates between 2 units/order and 4 units/order.

However, when the time between the arrival orders reduces to 3 days, most of the characteristics desired by the customer are not met and the sales rate falls. Following the step E of figure 1, the base model of figure 2 is constructed. Its simulation for 10 orders with a time between orders of 3 days generates the behaviors of figures 3 to 7 and table 4. These dynamics are far from those desired by the customers generating the decline of the customer order size (figure 6).

Following the steps indicated in blocks F to I of figure 1, two profile changes that generate the desired characteristics of the product were obtained (figures 3 to 7 and table 4). The first profile change (table 3 in figure 8) consists of reducing the assembly delay to 1.25 days/unit. In addition, this delay becomes independent of the number of parts waiting to be assembled. The second profile change (table 4 in figure 8) consists of always producing good assembled products.

The obtained profile changes can be implemented in many ways (table 1) and a detailed study of each possible implementation must precede the final choice. For example, the first profile can be implemented using assembly line organization with multiskilled operators and undercapacity scheduling (in order to reduce the assembly delay) and a total productive maintenance program (in order to make the assembly delay independent of the number of parts waiting to be assembled). The second profile change can be implemented using a zero defect quality control system for inspecting all the parts to be assembled.

4. Conclusions.

Empirical studies show that American and European firms implement prototypes of the japanese JIT system. However, the currently available tools to design these JIT prototypes are not very powerful. In this paper a new tool that applies system dynamics principles, using a continuous-discrete simulation language, was presented. This tool guarantees the

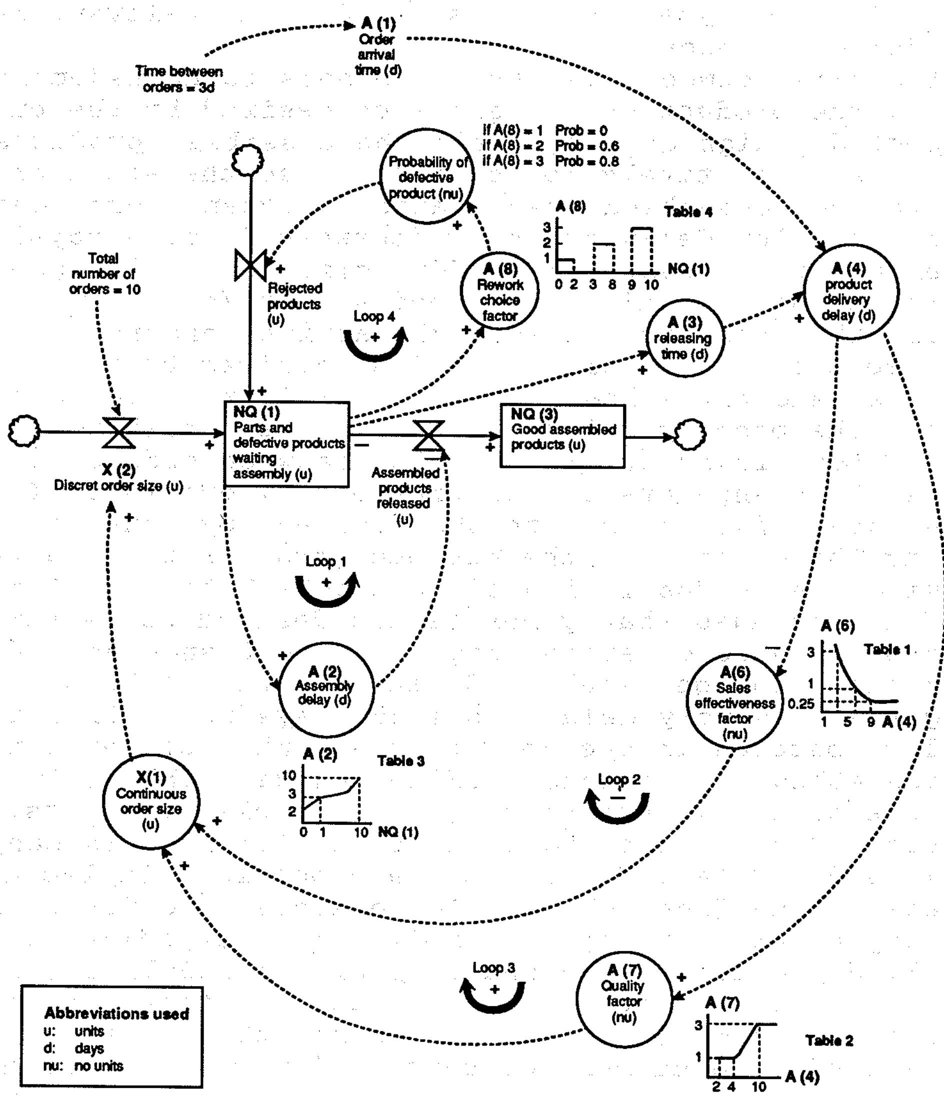


Figure 2. Cause-effect diagram of the system that generates the current characteristics of the product (Base model).
The customer order size depends of two factors, the sales effectiveness and the quality of the product. In addition, these factors depend on the product delivery delay (tables 1 and 2). On the other hand, more long is the queue of components waiting for assembly, less frequently are the machines maintained breaking more frequently and producing a more long assembly delay (table 3). Finally, the quality of the components is verified by sampling procedures before they enter into the assembly line. More long is the queue of waiting components, less efficient is this verification producing more defective assembled products (table 4).

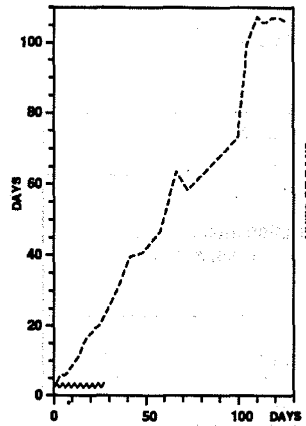


Figure 3.
Individual product delivery delay. Obtained by simulating a) The base model (———) and b) The base model with the structural changes added to it (———).

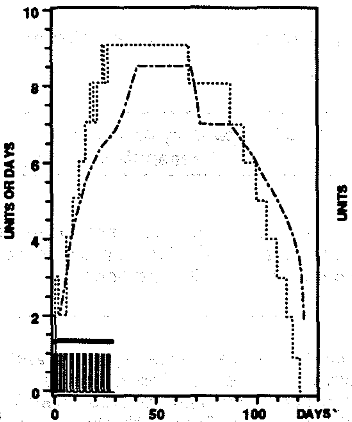


Figure 4.
Number of parts and defective products waiting for assembly. Obtained by simulating a) The base model (········) and b) the base model with the structural changes added to it (———). Assembly delay. Obtained by simulating a) the base model (— - —) and b) the base model with the structural changes added to it (▬▬▬).

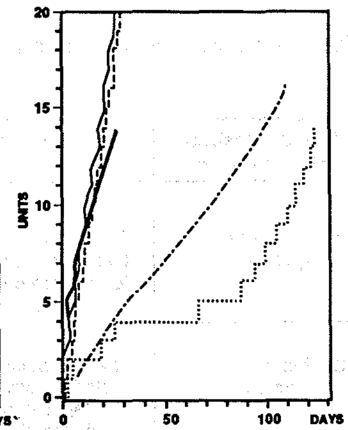


Figure 5.
Number of products ordered. Obtained by simulating a) the base model (—) and b) the base model with structural changes added to it (——). Number of good products assembled. Obtained by simulating a) the base model (······) and b) the base model with the structural changes added to it (– – –). Number of defective products reassembled obtained by simulating the base model (— · —).

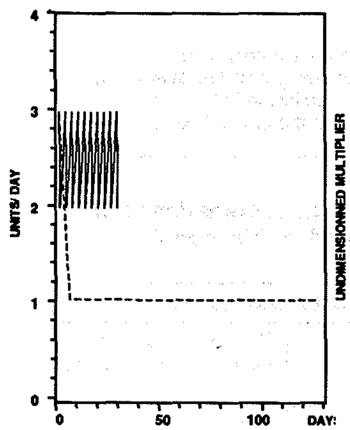


Figure 6.
Customer order size. Obtained by simulating a) the base model (———) and b) the base model with the structural changes added to it (——).

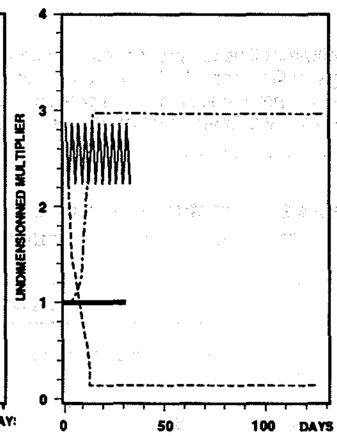


Figure 7.
Sales effectiveness factor. Obtained by simulating a) the base model (– – – –) and b) the base model with the structural changes added to it (———). Quality factor. Obtained by simulating a) the base model (—·—·—) and b) the base model with the structural changes added to it (——).

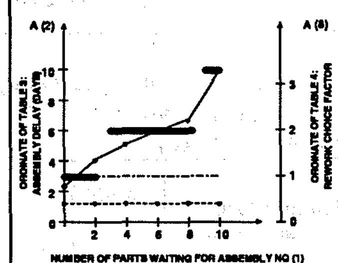


Figure 8.
Table 3 a) In the base model (———) b) Modified so that the problematic system generates the product desired characteristics (– – –).
Table 4 a) In the base model (▬▬▬) b) Modified so that the problematic system generates the desired product characteristics (— - —).

Table 2. Subset of system dynamics principles

1) The goal-oriented principle: Before building any model, identify a problematic (s) behavior (s). A behavior is problematic when it differs from a desired one.	2) The systemic principle: Begin the construction of the model at the problematic (s) behavior (s) and include in the model all the factors whose interactions generates the problematic (s) behavior (s).	3) The endogeneous principle: Include in the model the true sources of the problematic (s) behavior (s). In fact, the desired strategy consists of properly modifying these sources.	4) The adaptive aggregation principle: Use in the model a level of detail enough to reproduce the problematic (s) behavior (s). It is not necessary to model each part of the problematic system in detail, adequate aggregation must be used when necessary.	5) The structural principle: Include in the model the closed and the open cause-effect relationships that link the factors which cause the problematic (s) behavior (s).

Table 3. Current product characteristics desired by the customers

Product desired characteristic	Coefficients that partially capture the product characteristics in the manufacturing system
1) **Maximum quality**	Defects rate; Reworking rate; Number of post-guarantee interventions; Quantities of corrective work; Rate of customers complaints; Average time to repair returned products; Intervention time.
2) **Minimum price/cost**	Average stocks of materials, work in process and finished products; Materials, work in process and finished products turnovers; Percentages of shortages of scheduled material for production; Machines downtime; Machines utilization ratio; Space utilization; Employee hours worked exceeding target levels; Employee absenteism rate; Percentage of goods shipped on time.
3) **Minimum delivery delay**	Mean delivery time; Mean delivery delay; Percentage of products shipped on time.
4) **Maximum variety**	Number of different finished product codes offered; Number of product codes in a given time period; Time to convert to new production levels; Time to introduce new products; Number of products realisable in the minimum planning horizon; Maximum number of changes in the product design.

Table 4. Values of the coefficients that capture the product characteristics in the base model and when the structural changes are introduced in this model (u=units ; d=days)

Product desired caracterictic	Coefficient that partially capture the product caracterictic	Value of the coefficient in:	
		The base model	The base model with the structural changes included
1) **Maximum quality**	Number of products made good at the first trial	6 u (SIMAN output)	20 u (SIMAN output)
	Number of defective products reassembled	16 u (fig 5)	0 u (fig 5)
2) **Minimum price/cost**	Number of parts and defective products waiting for assembly (stocks)	min: 0 u max: 9 u average: 6.64 u (fig 4)	min: 0 u max: 1 u average: 0.42 u (fig 4)
3) **Minimum delivery delay**	Individual product delivery delay	min: 2 d max: 107.5 d average: 56.11 d (fig 3)	min: 1.25 d max: 2.50 d average: 1.88 d (fig 3)
	Makespan	124 d (fig 5)	29.5 d (fig 5)
4) **Maximum market share**	Total number of products ordered	14 u (fig 5)	20 u (fig 5)
	Order size	average: 1.14 u (fig 6)	average: 2.5 u (fig 6)

coherence of the JIT prototype components before their detailed designs. This tool must be used on a regular basis to keep improving the manufacturing system as suggests Mazaaki (1986).

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