"ADVANCED MANUFACTURING SYSTEM DYNAMICS: THE LEAN PRODUCTION APPROACH"

AUTHORS

Rafael RUIZ USANO
Adolfo CRESPO MARQUEZ
José Manuel FRAMIÑAN TORRES

Dpto. Organización Industrial y Gestión de Empresas
Escuela Superior de Ingenieros Industriales
Universidad de Sevilla
Avda. Reina Mercedes s./n.,
41012 - SEVILLA (SPAIN)
Fax : +34-5-4556883
E-Mail : usano@esi.us.es

ABSTRACT

The goal of this paper is to present some of the latest advances in manufacturing techniques. With that purpose, different production process patterns are modelled. The models are tested to carry out the experiments and further appropriate analysis for several manufacturing techniques. The techniques under study are known as "CONWIP", an acronym for Constant Work In Process and the very well known "JIT", Just In Time. The analysis is focused to obtain a deeper understanding of the Lean Production.

1. Introduction.

Lean Production techniques have to be developed if we want to provide the competitive advantage to companies. The key benefits of Lean Production (Womack et al,90) such as, less time and effort required to design a new product, lower production runs, better components by giving responsibility for design and quality to all people involved in it, and no stocks of components in the assembly plant as well as better coordinated production allows "just in time" deliveries of items which have to be understood and incorporated into the production planning process.

The introduction of Lean Production in a plant can be accomplished by using a specific manufacturing technique to obtain the expected results from every process, thus achieving the desired goal of the company. Sometimes a mixture of these techniques may be the best alternative for a particular production environment.

The models that constructed and simulated in this paper try to reproduce those situations and complexities faced by companies. To do this, several push and pull models are simulated to study as a whole some of the manufacturing characteristics of Lean Production. Specially, those related to using a production control system of the pull type.

In Section 2 the JIT/KANBAN, CONWIP and PUSH models are constructed. To test and compare the behaviour of the system both, the Throughput and the Inventory Levels are evaluated. The CONWIP model proves to have, in most cases, the best behaviour according to the present criteria.

The results of the simulation are presented in Section 3, in the form of tables and graphics which show the evolution of the selected variables versus the Throughput for different experiments. The simulation has been carried out using a interactive graphics simulation tool. The simulation runs were conducted for 60.000 time units with a warm-up period of 10.000 time units in order to minimize the initial transient effects.

Finally, Section 4 is dedicated to the preliminary conclusions obtained through this research and highlights the philosophy of Lean Production as a promising approach to gain a competitive advantage.

2. Modelling the JIT/KANBAN, CONWIP and PUSH systems.

The systems under comparison are JIT/KANBAN, CONWIP and PUSH. The performance of the systems will be measured by the throughput and the inventory levels. The goal, according to Lean Production principles, is to achieve maximum throughput with minimum inventory levels.

JIT/KANBAN is the best known pull system. It seems to produce superior results in environments where it can be applied. Unfortunately it is difficult, if not impossible, to use (Monden, 1983) when there are significant scrap losses, set-ups, job orders with short production runs, or unpredictable fluctuations in demand.

The JIT/KANBAN system is modelled as shown in figure 1. Workstation MAQ is allowed to start production if the inventory BUFF is less than or equal to one unit. Production is stopped if the inventory reaches a specified value, the number of kanban (NK). The number of kanban will be used in the experiments as the control system variable.

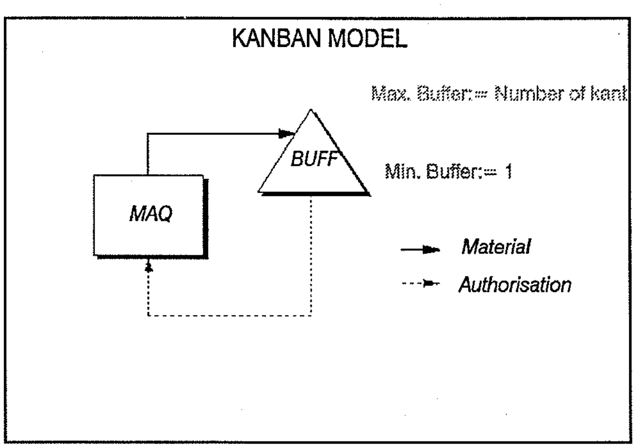


Figure 1. KANBAN model

CONWIP is described (Spearman, Hopp & Woodruff, 1990) as a long-pull system in which cards are attached to the production line instead to a single workstation. Parts are assigned to the cards at the beginning of the production line. When the part arrives to the end of the line, the card is sent back to the beginning of the line to be attached to another entering part. The start of work without a card is not allowed, even if the first workstation is idle. This mechanism limits the WIP in the line, but does not limit individual buffers, as in the case of JIT/KANBAN. Figure 2 shows the CONWIP model used in the experiments.

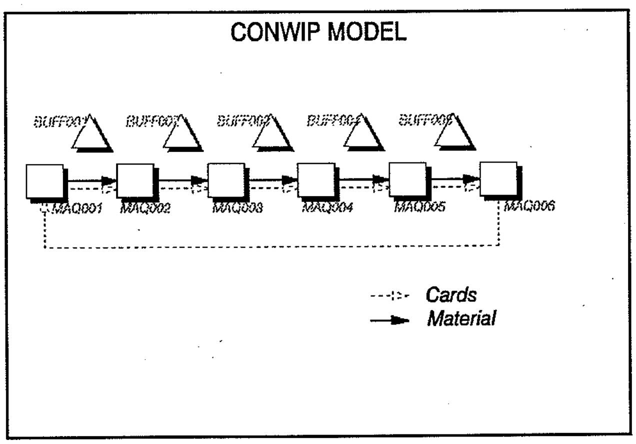


Figure 2: CONWIP model

CONWIP seems to share most of the benefits of the pull systems, like short flow times or reduced WIP levels. Furthermore, it can be applied in environments where other pull systems ,such as JIT/KANBAN, cannot. One example is a mixed product environment. It is well known that JIT/KANBAN has problems with product mix changes, since the number of kanban must be constantly adjusted. Yet, the number of cards in CONWIP is not related to the mix product.

The third system is a pure push system where the buffers capacity is limited. The purpose is to avoid the system clogs with WIP. An equal distribution of the buffers capacity is the best design in a balanced line (Conway, 1988). Thus, a maximum inventory level will be used for each workstation in the production line.

To test the performance of the systems, three different experiments have been designed. In all of them it is assumed that there is always a supply of raw materials to start production, and also that there is a customer for every part produced, so the system is never starved or blocked. Consequently, there is no need to model a finished goods inventory, so the number of required buffers in an experiment with n workstations will be $n-1$.

In the first experiment a typical assembly type of production line is simulated. The same experiment can be found in Lambrecht & Seagert (Lambrecht & Seagert, 1990). Figure 3 shows the configuration of the line. There are eight work centres, each with an exponential cycle time. The mean cycle time is 10 time units, while the coefficient of variation is 0.1. Centres MAQ003 and MAQ006 feed centre MAQ007. For designing the CONWIP system, two branches for the cards have been designed. The first branch involves work centres MAQ001-MAQ002-MAQ003-MAQ007-MAQ008 while the other MAQ004-MAQ005-MAQ006-MAQ007-MAQ008.

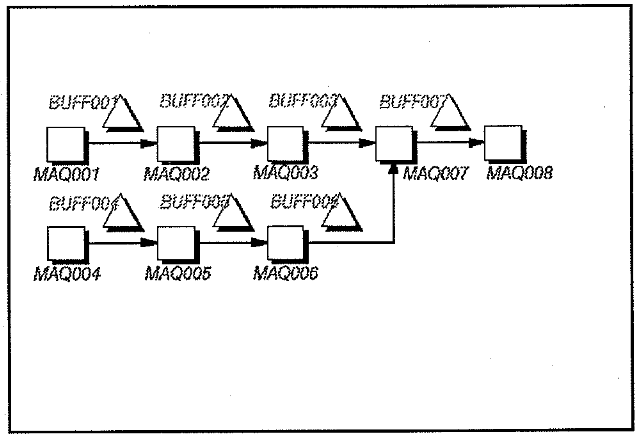
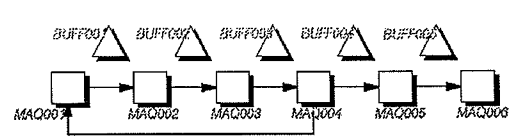


Figure 3: Assembly

The second experiment has been designed to illustrate the influence of the bottleneck on the performance of the systems. We will test the line drawn in figure 4, where the mean cycle times are shown below. Workstation MAQ004 is the bottleneck, with a mean cycle time of 15 units. The used distribution is an exponential one, and again the coefficient of variation is 0.1.



Average Cycle Time

MAQ001	MAQ002	MAQ003	MAQ004	MAQ005	MAQ006
9	9	9	15	9	9

Figure 4. Long-pull and bottleneck

In this experiment CONWIP will be tested in both its original design and in a different one pointed out by Spearman *et altri* (Spearman, Hopp & Woodruff, 1990) for environments with a distinct and permanent bottleneck. In these cases, cards are sent to the beginning of the production line as soon as the bottleneck processes the part. Workstations downstream from the bottleneck, push the parts to the end of the line. The situation resembles the DBR's (Goldratt, 1990) more general approach.

Finally, a third experiment including scrap loss situations has been set. In this experiment, there are six workstations with an average cycle time of 10 time units drawn from an exponential distribution. The coefficient of variations is also 0.1. In this experiment it is supposed that a percentage of parts should be sent to scrap due to workstations unrealiability. For the CONWIP system this means that when the part is sent to scrap the card is also removed and attached to a new part at the beginning of the production line. For this experiment, only JIT/KANBAN and CONWIP systems are compared.

Modelling was done with WITNESS 6.10. The simulation runs were for 60.000 time units. To minimize transient effects, a 10.000 time units warm-up period has been set. Five replications of every experiment have been simulated. In each replicate, a different stream for the pseudo-random stream numbers is used. In the third experiment, the random stream utilized for parts sent to scrap is different in each workstation and also different to the streams used for the cycle time distributions.

For the JIT/KANBAN system the control variable is the number of kanban. For CONWIP it is the number of cards, while the control variable for the push system is the buffers capacity. In each experiment, for every system a number of simulations have been run to obtain several pairs throughput - inventory level.

Experimental analysis has been conducted using WITNESS XA.

3. Simulation Results.

Figure 5 gives the findings in the first environment -the assembly production line-. The superiority of CONWIP over the PULL and JIT/KANBAN system is proved. For a given throughput, CONWIP requires lower inventory levels, while achieving higher throughput for a given inventory level. Furthermore, CONWIP performs better when a higher throughput is required -when system must operate near full capacity-. JIT/KANBAN is the system that offers the poorest performance, although it may be used before that PUSH system when inventories should be kept to low levels.

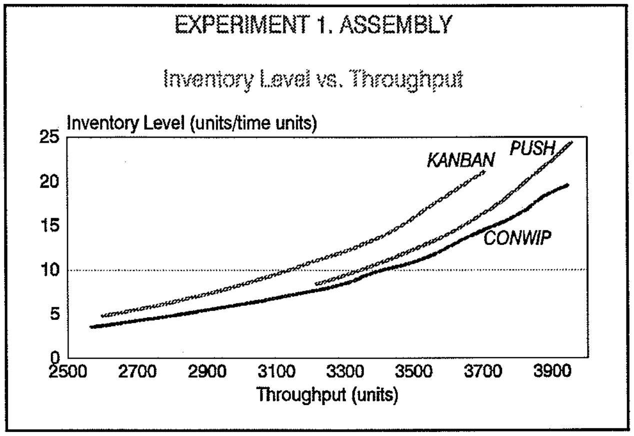


Figure 5

Also in a line with a defined bottleneck CONWIP provides optimal combinations of high throughput with low inventory levels, specially when it is modified to resemble the DBR philosophy. Optimal results for each system are presented in figure 6:

EXPERIMENT 2: BOTTLENECK

Production System	Throughput	Inventory Level	Control Variable
PUSH	3335	6	Buff. Max.: 1
KANBAN	3334,4	3,733	N. of kanban: 3
CONWIP	3332,6	2	Cards: 6
CONWIP* (DBR)	3335	1,199	Cards: 4

Figure 6

When there is significant scrap loss (experiment 3) the effectiveness of CONWIP decreases. For the production line designed in the third experiment CONWIP appears to be superior to JIT/KANBAN when there is no scrap loss in the line.

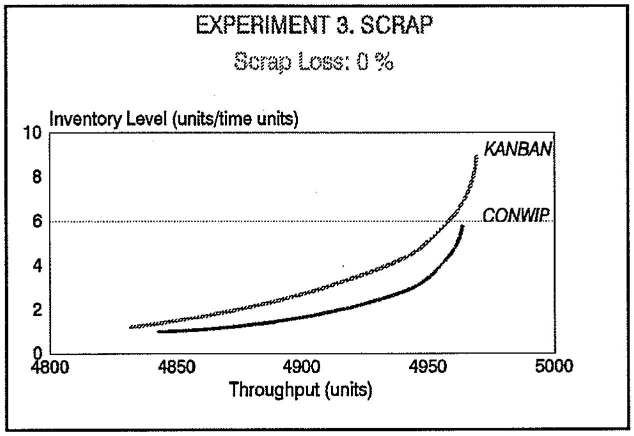


Figure 7

As it is shown in figure 7, CONWIP yields higher throughput for a given inventory level, or reaches the same throughput that JIT/KANBAN with lower inventory levels.

When increasing the percentage of parts sent to scrap the CONWIP advantage over JIT/KANBAN disappears, as it is observed from figure 8. The explanation can be found in the alternative routes for the cards that the scrap loss introduces. Some of the cards pass through the whole line, while a percentage of cards circle around the first workstation, and another percentage around the first and second workstations and so on. Thus, the CONWIP mechanism that encompased the production rate to the introduction of new parts to be processed is broken. The results are, decreasing throughput while increasing inventory levels.

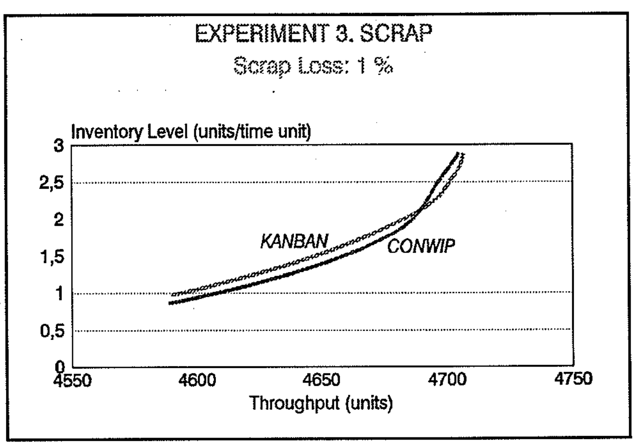


Figure 8

4. Conclusions.

In this paper three manufacturing techniques have been analysed, namely CONWIP, JIT/KANBAN and MRP, in order to obtain a deeper knowledge of some processes faced frequently in the manufacturing environment. Three experiments have been set to illustrate the behaviour of the system being studied. Although important questions have yet to be answered, the conclusions below aim to highlight some of the manufacturing characteristics of Lean Production. A comparative study focused mainly on the CONWIP and KANBAN systems has been carried out.

The CONWIP system was created as a generalized form of KANBAN. Here the cards are attached to a production line instead of to a single workstation. This provides more freedom in the allocation of the buffers, and the system maintains a WIP that moves to where it is required.

CONWIP can be applied in environments where KANBAN cannot, such as a mixed product one. It is also possible to be extended to an assembly type of production, achieving more throughput while requiring less inventory.

CONWIP can be easily transformed into a DBR system in environments with a distinct bottleneck. As a matter of fact, CONWIP and DBR share many characteristics. The role of "*Rope*" in a CONWIP system is played by the number of cards.

The number of cards encompases the production rate. This is the reason for the poor performance shown by CONWIP when there are scrap losses in the line. Scrap losses "create" new routes for the cards that break the "Rope" mechanism.

CONWIP has confirmed most of its expectatives to be a PULL system that shares KANBAN's benefits with the possibility to be applied in environments that KANBAN cannot. Thus, it seems to be appropriate for situations where lines must operate near full capacity. It is more robust than the KANBAN system when the production is not completely stable and predictable, maintaining the advantages of PULL systems over PUSH ones. Important questions like CONWIP's parameters analysis and backlog sequencing remain to be answered.

5. References.

Conway, R., Maxwell, W.,McClain,J. and Thomas, J.
"The Role of Work-In-Process Inventory in Serial Production Lines"
Operations Research. 1988, Vol. 36, No. 2, pp. 229-241.

Goldratt, E.M.
The Haystack Syndrome
North River Press. 1990

Lambrecht, M. and Seagert, A.
"Buffer Stock Allocation in Serial and Assembly Type of Production Lines"
International Journal of Production Management. 1990, Vol. 10, No. 2, pp. 47-61.

Monden, Y.
Toyota Production System: Practical Approach to Management
Industrial Engineering and Management press. Norcross. 1983

Spearman, M.L., Woodruff, D.L. and Hopp, W.J.
"CONWIP: a pull alternative to kanban"
International Journal of Production Research. 1990, Vol. 28, No. 5, pp. 879-894.

Womack, J.P., Jones, D.T., Roos, D. and Carpenter, D.S.
The Machine that Changed the World
Macmillan Publishing Company, USA. 1990