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SELECTING A TOKEN-BASED CONTROL SYSTEM USING TAGUCHI METHODS

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Abstract

Token-based control systems have been widely used in manufacturing systems and studied by researchers in the last decades. The most well-known token-based control systems are Kanban and Conwip, although there are others that have been developed recently. Although several comparisons among these systems regarding a number of performance measures have been conducted and described in the relevant literature, they show that no single system can be considered to outperform the others for all manufacturing scenarios. Besides, given the stochastic nature of the manufacturing environments, it is of interest to select a control system based on its robustness with respect to a given criterion or set of criteria. Since Taguchi methods are well-known techniques for the design and selection of different systems according to robustness criteria, in this paper we apply Taguchi methods to select the most robust token-based control system in manufacturing scenarios characterised by rework, different target service levels and non balanced production lines.

1.- Introduction

Token-based production control systems have been widely used from practitioners and studied from researchers during the last decades. A token-based production control system is a production control mechanism that employs token signals in order to control the Work In Process (*WIP*) in the system (Gershwin, 2000). The most popular token-based system is

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Kanban (see e.g. Sugimori, 1977), although other production control systems employ this kind of token signals, such as Conwip, Base Stock, Generalized Kanban, Generic Kanban, Extended Kanban, and Hybrid Kanban-Conwip. Most of these systems been applied on real manufacturing environments and compared with each other under different manufacturing conditions. If we compare the performance of two systems can occur that the first system operate better than the second working under certain scenario, while the second can operate better than the fist working in another different scenario. Then we could say that no one system outperforms the others on every possible situation. However there are only a few comparison among token based control systems for certain scenarios (see Framinan *et al*, 2003 for a summary of comparisons among different production control systems). On the other hand we have to notice that there are some uncertainty factors that can affect the performance of the system (for example the target service level, the degree of imbalance (*DI*) or the percentage of re-work). Could be interesting determine the production control system that works better under the uncertainty manufacturing conditions.

On the other hand, it is known the importance of Taguchi methods as a tool to select among different products, process or services (see e.g Moeeni, 1997). Taguchi methods are based on *off-line quality* trying to identify the products, process or services which are robust in the sense that are less variable under environmental conditions. This method uses a signal to noise ratio to select the most robust product or process (see e.g. Taguchi and Wu, 1980 or Taguchi, 1986). Although Taguchi methods are not free of criticism, they have been successfully applied on a great variety of industrial environments.

The aim of this work is to apply Taguchi methods to select the most robust production control system among the different token-based control systems working under different noise conditions (target service level, degree of imbalance and percentage of rework).

The remainder of the paper is organised as follows: In the next section the main token-based production control systems are described. Next, we show the experimental conditions, considered scenarios, and results obtained applying Taguchi methods. Finally, the last section is devoted to draw conclusions and point out future research lines.

2.- Literature review of Token-based control systems

We use a flow-shop line formed by N stations to describe the performance of the different systems (see figure 1). In subsequent figures, continuous lines represent jobs flow through the line, while doted lines represent the information flow or cards flow. Every station consists in one input buffer (IB), one machine (M) and one output buffer (OB). The notation is the following:

$IB_i(t)$: number of jobs in the input buffer of station i at instant t

$OB_i(t)$: number of jobs in the output buffer of station i at instant t

$M_i(t)$: number of jobs in station i at instant t

We can consider the Work In Process of kth station, $WIP_k(t)$ as the number of jobs contained in the input buffer, plus those contained the output buffer and the jobs actually processed (see equation 1). For simplicity we only describe the different control mechanisms for one type of job.

$$WIP_i(t) = IB_i(t) + OB_i(t) + M_i(t) \quad (1)$$

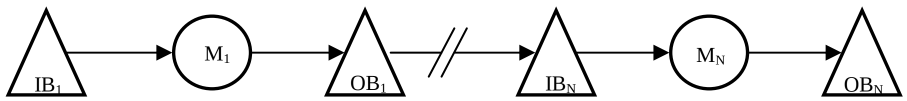

Figure 1. Production line

Each one of the different token-based control systems are described in the following subsections.

2.1.- Kanban

One of the earliest descriptions of the Kanban system is provided by Sugimori *et al.*, (1977), and a relatively recent review on Kanban systems is the work by Berkley (1992). Kanban systems are based on a blocking mechanism that depends on the maximum buffer capacity. Roughly, Kanban systems can be classified in two different types: Single Kanban and Dual Kanban. In the next subsections, both systems are described.

2.1.1 Single Kanban

For this system, the WIP in the kth station, $WIP_k\ (t)$ must be less that a certain quantity, determined by the number of kanban cards, NC_k. A kanban card is attached to a job whenever it enters the input buffer, and the card is withdrawn when this job exits the output buffer. New jobs only can enter the system if there are available cards to be attached to these jobs. This mechanism is termed 'Instantaneous Material Handling' (Berkley, 1992) or 'Immediate Material Transfer' (Gstettner and Kuhn, 1996).

In this system the material handling between the output buffer of a station and the input buffer of the next station is instantaneous, and it is equivalent to consider only one buffer between stations. The decision variables regarding each station in a Single Kanban are the number of kanban cards on every station, NC_k. Figure 2 shows the jobs and cards flow in a instantaneous material handling system, between stations kth and k – 1-th,

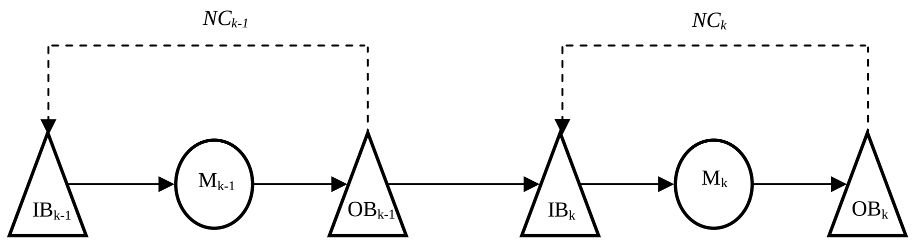

Figure 2. Single Kanban (Immediate Material Transfer)

2.1.2 Dual Kanban

This system is similar to Single Kanban, but the main difference lies on the material handling process between intermediate buffers. In this case, material handling is non instantaneous, but carried out in two different ways: in the first case, transportation between buffers occurs when the number of jobs in the output buffer reaches a fixed quantity (order point). This system is denoted as Dual Kanban by order point. In the second case, material handling is carried out by means of fixed withdrawal cycles or Kanban periods (Monden, 1983). We refer to this system as Dual Kanban by fixed period. Other authors refer to this system as 'Non instantaneous Material Handling' (see e.g. Berkley, 1992).

In the first case, two types of cards are considered: one type of cards is devoted to production (production kanbans), while another type of cards is associated to transportation between intermediate buffers (transportation kanbans). Transportation between the output buffer of station $k-1$th and the input buffer of station kth occurs whenever the number of jobs (or containers) in OB_{k-1} equals NTC_{k-1}.

In second case is also employed a type of cards for production, but now the cycle time for transportation between intermediate buffers, NTC_{k-1}, must be set. In this case the number of jobs can fluctuate in different periods.

The number of transportation cards is usually established by means of a certain cost function, taking into account inventory holding costs and transportation costs (Berkley, 1992).

Figure 3 shows both, Dual Kanban by order point and Dual Kanban by fixed withdrawal cycles.

Decision variables concerning every station are the number of production cards , NPC_k, and the number of transportation cards, NTC_k, for the first case and the withdrawal cycle time, TCT_k, in the second case.

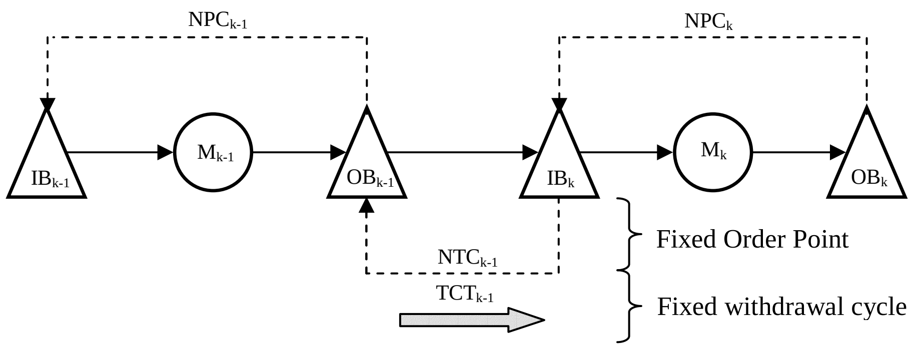

Figure 3. Dual Kanban system

Kanban system is related to the *Tandem Buffer System*. Tandem systems are based on blocking mechanisms when the number of jobs reach the maximum capacity of the output buffer. However, there are two different versions: *Blocking by total queue size* (*Manufacturing blocking* o *Tandem queue* -Perros and Altiok, 1986-) and *Minimal blocking* (Mitra and Mitrani, 1990). In first case the blocking mechanism is triggered when the job actually processed is going to reach the maximum capacity of the output buffer. The job wait at station, blocking the entrance of other jobs. In second case job stay at output buffer, while the station is now free to process another job. Mitra and Mitrani, 1990, show that Minimal blocking system is equivalent to Kanban system.

2.2 Conwip

The Conwip –Spearman *et al.*, 1990- (CONstant Work In Process) production control system tries to maintain constant the maximum amount of work in process in the system. This control system is implemented by means of kanban cards. One kanban card is attached to a job from the beginning of the line. The maximum work in process equals the total number of cards in the system. When a part is shipped to the system, the attached card is released and is sent to the beginning of the line, where it will be attached to another job to be processed.

The variable concerning this system is only one, the number of kanban cards, *NC*. Figure 4 shows the system, for a line formed by three stations.

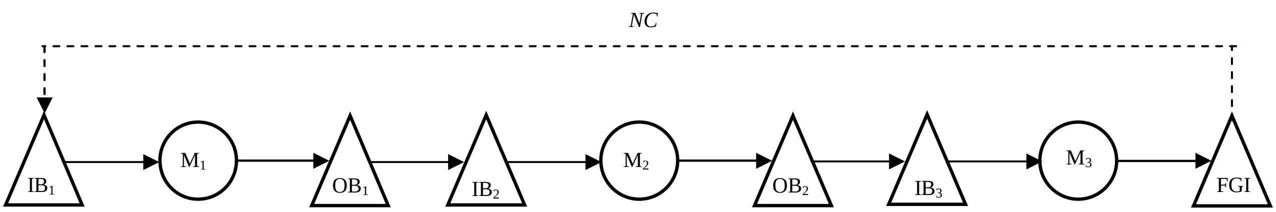

Figure 4. Conwip system

2.3 Base Stock

This production control maintains a certain amount of inventory in the input buffer on each station. The amount of inventory is called *base stock level*, S_i, on each station. The input signal is caused when a customer arrives. An individual station can produce only in the case that a customer demand signal arrives to the station and the number of parts in the output buffer is less than a certain quantity, S_i . Otherwise the system remains blocked. The variables concerning this system are the base stock level, S_i, on each station.

The system is shown in the figure 5, for a line formed by three stations.

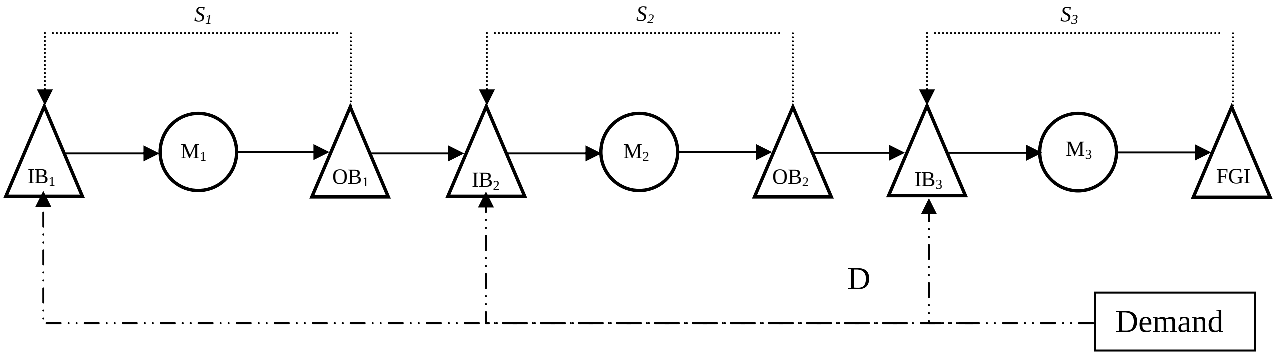

Figure 5. Base Stock

Some authors propose implementing the customer demand signal by means of cards flow signals (see Bonvik *et al.* , 1997 or Gaury, 2000). Figure 6 shows a Modified Base Stock control system for a line formed by three stations. The variables concerning this system are the number of cards to each station, NC_k.

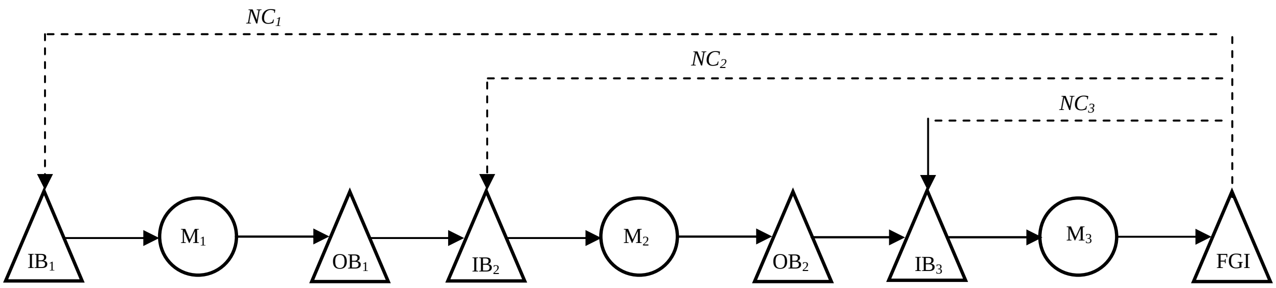

Figure 6. Modified Base Stock

2.4 Generalized Kanban

Generalized Kanban (see Buzacott, 1989, Zipkin, 1989 or Frein *et al.*, 1995) is a hybrid combination of Kanban system and Base Stock and results similar to Extended Kanban (see section 2.5). The *k*-station of this system can produce if WIP_k (t) is under certain quantity (NC_k) and the number of parts in the output buffer, OB_k (t), is less than a certain quantity, (S_k).

This system is like a Single Kanban system, although it consider a base stock level, S_k, on each station (see figure 7).

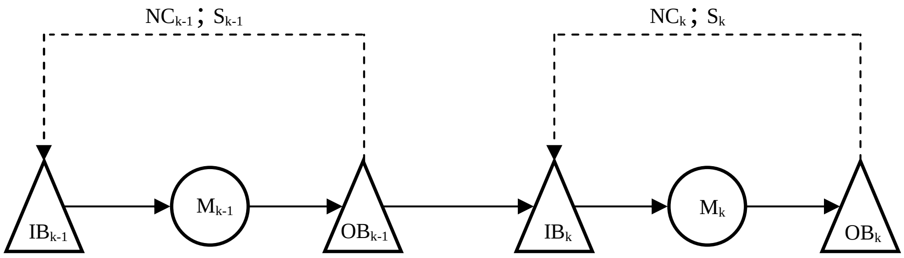

Figure 7 Generalized Kanban

The decision parameters concerning to the Generalized Kanban are the number of cards, NC_k, that control the total *WIP* of the stage, and, S_k, which determines the target in terms of the number of products that must be produced to be stored at the output buffer.

2.5 Extended Kanban

This system is also a hybrid combination of Kanban system and Base stock (see section 2.3) like the Generalized Kanban system. The main difference between Extended Kanban and Generalized Kanban is that in the former, the customer demand signal is instantaneously transferred to all stations, while in the latter it is a non-instantaneous process (Dallery and Liberopoulos, 2000).

An individual station can produce only in the case that simultaneously there are available kanban cards, the number of parts in the output buffer is under certain quantity, S_i, and a customer demand signal arrives to the station. In other case the system remains blocked.

Figure 8 shows the Extended Kanban system. For simplicity we consider a tandem production line formed by two stations.

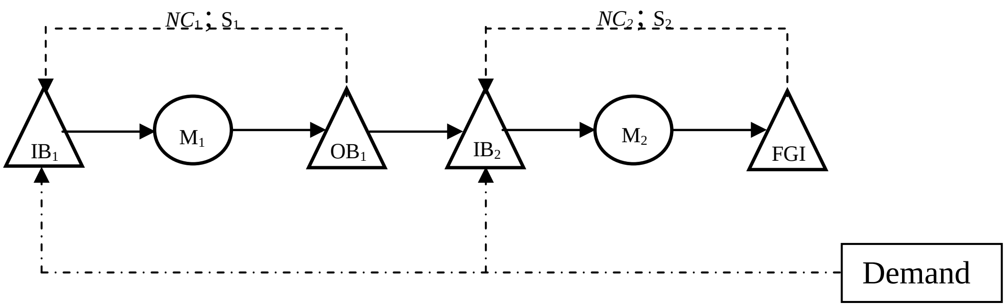

Figure 8. Extended Kanban

The decision variables concerning each station on Extended Kanban systems are the number of cards to each station, NC_i, and the base stock level, S_i, as in the Generalized Kanban system.

As in the Base Stock system (see section 2.3), the customer demand signal can be implemented by means of a cards flow. Then two types of kanban cards are attached to the station. One kanban controls the *WIP* in the station and the other makes a production signal (as a customer demand signal). The station can only produce if there is at least one of each type of cards to be attached to a new job.

The decision variables concerning each station on Extended Kanban systems are the number of cards to each station, NC_k, and the number of cards from demand loops, NDC_k. Figure 9 shows the Modified Extended Kanban.

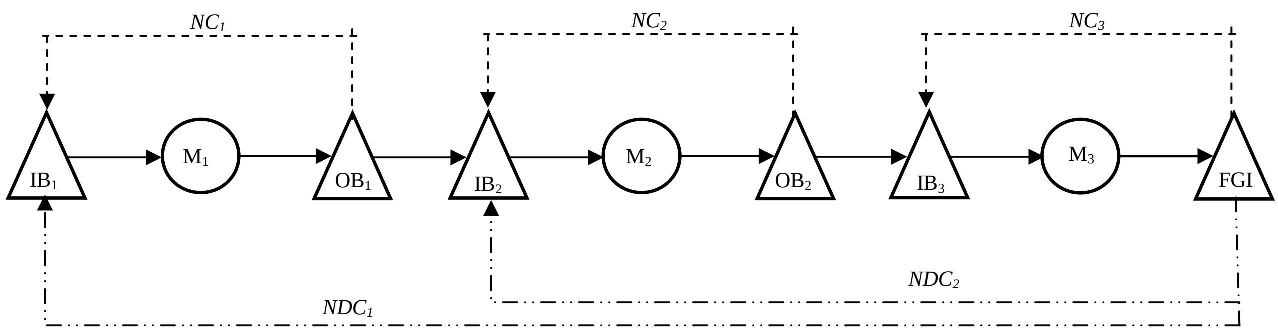

Figure 9. Modified Extended Kanban

2.6 Generic Kanban

Chang and Yih, 1994, proposed a modified Kanban system for dynamic environments, that is, for high variability on process times and demand uncertainty. Although the term is similar to 'Generalized Kanban' (see section 2.4), both systems are rather different. In this system there is only one card flow control for each station. But the difference with respect to the Single Kanban system is that the control loop is established between the output buffer for each station and the first station, as shown in the figure 10 for a line formed by three stations.

When a job is processed in one station, the attached card is released and sent to the first station. In this case the first station can only process a job/container when there is at least one type of kanban cards. Otherwise the first station remains blocked. The rest of the stations can produce whenever a new job arrives to the input buffer and the machine is not busy processing another job. The decision variables concerning this system are the number of cards, NC_k, for cards flow between each station and the first one.

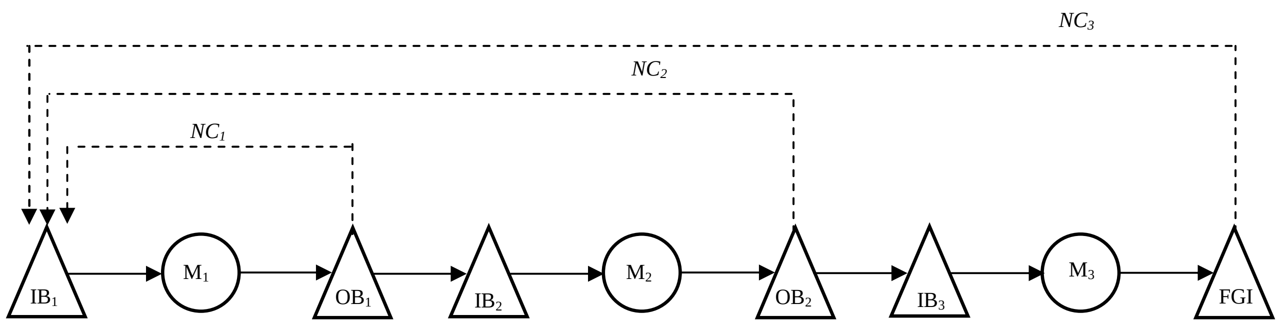

Figure 10. Generic Kanban

2.7 Hybrid Kanban/Conwip

This system is a combination between Kanban and Conwip. It is also termed *"Two-boundary hybrid"* (Bonvik *et al.*, 1997). Figure 11 shows a hybrid Kanban/Conwip system formed by three stations. As it can be observed, it consists of a Conwip system with capacity restrictions in the intermediate buffers.

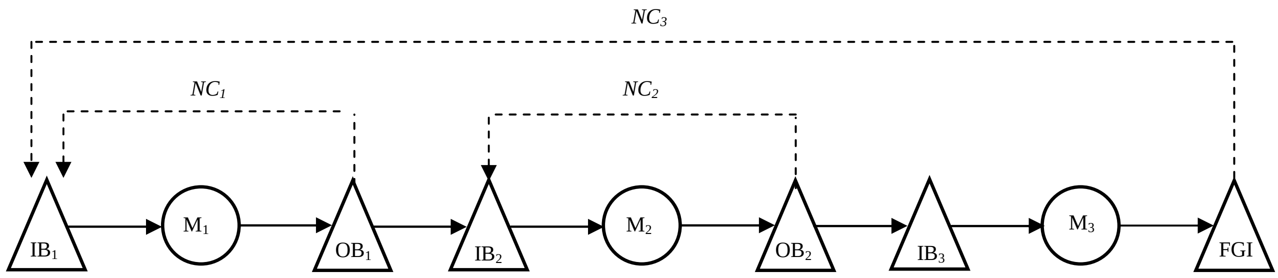

Figure 11. Hybrid Kanban/Conwip

The decision variables concerning this system are the number of cards related to each station, with the exception of the last station, and the number of cards from the last station to the first one (equal to the total WIP in the system).

3.- Experiments

In this section we describe a number of scenarios in order to analyse the performance of the described systems. To simplify the analysis, we have only considered the Single Kanban, Conwip, Modified Base Stock, Generalized Kanban and Generic Kanban systems. We have excluded the Extended Kanban system, given the great computational effort required for its optimisation. As we will show in the last section, this comparison could also be extended to different Kanban hybrid policies (such as Hybrid Kanban/Conwip, which is not considered in this work). On the other hand we have assumed only one intermediate buffer between stations, and for this reason we have excluded the Dual Kanban system.

In section 2 we show that the number of cards is the main parameter affecting the performance of a token based control system. In order to compare the performance of the systems is very important to get their best performance on each scenario. In other words, we must establish the correct number of cards for each system and scenario. To do this we optimise every system by means of exhaustive search, taking into account every possible combination of parameters. We apply this study to a line formed by 3 stations in tandem and one type of job.

To study the performance of the system under a variety of conditions we select three factors in two levels to characterise the scenarios: the degree of imbalance of the line, the target service level and the percentage of re-work.

It can be shown in literature that a common expression to describe the degree of imbalance is *DI* (see Meral and Erkip, 1991):

$$DI = max\{\ TWC / N - min\ (\ PT_i);\ max\ (\ PT_i\ ) - TWC / N\ \} * (\ N / TWC\ )$$

Where:

PT_i	is the processing time at station *i* in a line of formed by *N* stations
TWC / N	is the processing time at one station in a balanced line formed by *N* stations
TWC	is the total working capacity

In table 1 are shown some *DI* values appeared on literature:

Reference	***DI***
Villeda *et al.*, 1988	0.0 to 1.4 (step 0.2)
	0.0 to 0.7 (sep 0.1)
Meral and Erkip, 1991	0.0, 0.1, 0.2, 0.45
Yavuz and Satir, 1995	0.0, 0.1, 0.3, 0.5

Table 1. *DI* values

In our work we set *DI* in two levels: 0.0 or 0.1. We assume that the imbalanced station is always the second one. Processing times are exponentially distributed with means shown in table 2, for balanced and imbalanced scenarios:

	Station 1	Station 2	Station 3
Balanced	2,85	2,85	2,85
Imbalanced	2,85	3	2,85

Table 2. Mean process times on each station

Respect to the service level we do not consider backordered demand, i.e. we consider lost sales. Therefore we must set the service level near the 100%. We establish a target service level with two possible values: 95% and 98%. We assume that the customer demand inter-arrival time is exponentially distributed with mean 4.275. (It is important to notice that in a token based control system the number of cards must be increased in order to get a high service level. Then the computational effort increases with the service level. The chosen value for the customer inter-arrival times has been set in order to achieve the aforementioned service levels in a reasonable computation time).

In many manufacturing environments, it is usual to establish a Quality Control in one or various stations of the line. These controls can detect these jobs that must be re-processed. In this paper we consider two possible states with respect to the re-worked jobs. In a first case we assume no re-working, and in a second case we assume that 11% of jobs must be processed again on every station.

As a summary we show the levels of the noise parameters selected in table 3

	Coded value	-1	1
Factors	Re-worked jobs (%)	0	11
	Degree of imbalanced (*DI*)	0.0	0.1
	Service level (%)	95	98

Table 3. Noise factors and levels

Simulation parameters are established by means of pilot simulations on every system considered and a certain variety of scenarios. We select a run length of 10.000 time units, a warm-up period of 2.500 time units and 15 replications of the experiment in order to avoid the transient effect.

We run the simulations and select the optimum number of cards for each system and scenario. The optimal number of cards is selected as it produces the smaller average *WIP* while reaching the specified service level for the specified scenario.

On the other hand we select a L_8 array to introduce the selected noise values (See e.g. Wu and Wu, 1996). In the experiments we evaluate the average work in process, including a confidence interval of 99%. Results of *WIP* are shown in table 4.

		1	2	3	4	5	6	7	8	
NOISE FACTORS	**Run**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
	Re-work	-1	-1	-1	-1	1	1	1	1	
	DI	-1	-1	1	1	-1	-1	1	1	
	Service Level	-1	1	-1	1	-1	1	-1	1	η
SYSTEM	Single Kanban	8,94 ±0,24	12,31 ±0,27	9,33 ±0,14	12,81 ±0,37	10,74 ±0,76	16,01 ±0,33	11,45 ±0,39	17,15 ±0,40	-22,0395
	Conwip	9,06 ±0,09	11,86 ±0,10	9,09 ±0,06	12,75 ±0,08	10,59 ±0,09	14,23 ±0,10	11,54 ±0,10	15,28 ±0,20	-21,5732
	Modified Base Stock	8,14 ±0,08	10,89 ±0,09	8,47 ±0,05	10,90 ±0,09	9,81 ±0,08	13,29 ±0,13	10,58 ±0,12	13,78 ±0,06	-20,7467
	Generalized Kanban	8,54 ±0,19	11,63 ±0,35	9,06 ±0,37	12,01 ±0,37	10,30 ±0,30	14,82 ±0,40	10,46 ±0,38	15,33 ±0,39	-21,4014
	Generic Kanban	8,11 ±0,05	10,14 ±0,33	8,16 ±0,05	10,88 ±0,20	9,80 ±0,31	12,89 ±0,26	10,15 ±0,28	13,54 ±0,37	-20,5216

Table 4. Results of the experiments

In last column we include the value of the signal to noise ratio according to the following expression (see Wu and Wu, 1996):

$$\eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

Where,

η is the signal to noise ratio in decibels

n is the number of runs (8 in this case)

y_i is the response (average *WIP*) for a certain scenario

This expression is advised to be employed in systems which response should be minimised. For a different optimisation criterion other alternative expressions should be employed (see e.g. Wu and Wu, 1996). Figure 12 shows the results of signal to noise ratio obtained from table 4.

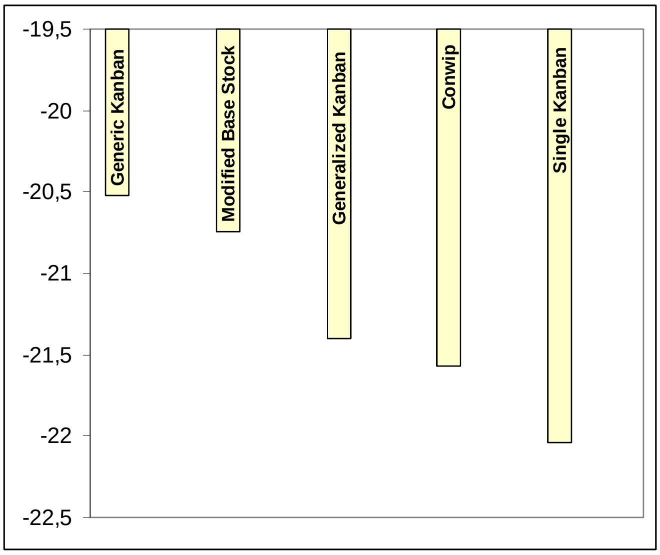

Figure 12. Results of signal to noise ratio

The results in Figure 12 show us that, regarding to the minimisation Taguchi Robust Design criterion, the Generic Kanban system outperforms the other systems for the considered scenarios and under variability conditions of target service levels, degree of imbalance and re-worked jobs. We must also take into account that Modified Stock Base system performs in similar way that the Generic Kanban system. On the other hand, Conwip and Generalized Kanban systems reach similar results. The worst results are obtained by the Single Kanban system.

4.- Conclusions

In this paper we have reviewed the main token based control systems. For each system, its control mechanism has been described. Next, we have discussed three factors that influence the performance of the systems, i.e.: the target service level, degree of imbalance and the percentage of re-work. After, we have compared the performance of different token based systems in order to select the most robust, given the variability of the manufacturing environment by means of Taguchi Robust Design. Under the considered conditions, the Generic Kanban system has proved to be the most robust token based system, while the worst results are achieved by the Single Kanban system.

Future research should consider additional token based systems, such us the hybrid systems and customised systems (Gaury, 2000) and extra noise factors such as machine breakdowns or backordered demand.

References

Berkley, B. J., (1992) "A review of the kanban production control research literature", *Production and Operations Management*, 1(4), 393-411.

Bonvik, A.M., Couch, C.E. and Gershwin, S.B., (1997) "A comparison of production-line control mechanisms", *International Journal of Production Research*, 25(3), 789-804.

Buzacott, J.A., (1989) "Queueing models of kanban and MRP controlled production systems", Engineering Cost and Production Economics, 17, 3-20.

Chang, T.M. and Yih, Y., (1994) "Generic Kanban systems for dynamic environments", *International Journal of Production Research*, 32, 889-902.

Dallery, Y. and Liberopoulos, G., (2000) "Extended kanban control system: combining kanban and base stock", *IIE Transactions*, 32(4), 369-386.

Framiñán, J.M., González, P.L. and Ruiz-Usano, R., (2003) "The conwip production control system: review and research issues", *Production Planning & Control*, 14(3), 255-265.

Frein, Y., Di Mascolo, M. and Dallery, Y., (1995) "On the design of generalized kanban control systems", *International Journal of Operations in Production Management*, 15(9), 158-184.

Gaury, E.G.A., (2000) "*Designing Pull Production Control Systems: Customization and robustness*", PhD Thesis, (*Ed. Center*).

Gerswhin, S. B., (2000) "Design and operation of manufacturing systems: the control-point policy", *IIE Transactions*, 32, 891-906.

Gstettner, S. and Kuhn, H., (1996) "Analysis of production control systems kanban and Conwip", *International Journal of Production Research*, 34(11), 3253-3274.

Hopp, W.J. and Spearman, M.L., (1996) "*Factory Physics*" (*Ed. Irwin, Chicago, USA*).

Meral, S. and Erkip, N., (1991) "Simulation analysis of a JIT production line", *International Journal of Production Economics*, 24, 147-156.

Mitra, D. and Mitrani, I., (1990) "Analysis of a Kanban discipline for cell coordination", *Management Science*, 36(12), 1548-1566.

Moeeni, F., Sanchez, S.M. and Vakharia, A.J., (1997) "A robust design methodology for Kanban system design", *International Journal of Production Research*, 35, 2821-2838.

Monden, Y., (1983) "*Toyota production system*", Industrial Engineering and Management Press, Atlanta.

Perros, H. G. and Altiok, T., (1986) "Approximate analysis of Open networks of queues with blocking: Tandem Configuration", *IEEE Transactions on Software Engineering*, SE-12, 450-461.

Sugimori, Y., Kusunoki, K., Cho, F. and Uchikawa, S., (1977) "Toyota production system and kanban system materialization of just-in-time and respect-for-human system", *International Journal of Production Research*, 15(6), 553-564.

Spearman, M. L., Woodruff, D.L. and Hoop, W.J., (1990) "Conwip: a pull alternative to Kanban", *International Journal of Production Research*, 28(5), 879-894.

Taguchi, G., (1986) "*Introduction to quality engineering: designing quality into products and processes*", White Plains, New York: Kraus International Publications.

Taguchi, G. and Wu, Y., (1980) "*Introduction to Off-line Quality Control*", Central Japan Quality Control Association, available from American Supplier Institute, Detroit.

Villeda R., Dudek, R. and Smith M.L., (1988) "Increasing the production rate of a just-in-time production system with variable operation times", *International Journal of Production Research*, 26, 1749-1768.

Wu, Y. and Wu, A., (1996) "*Diseño Robusto utilizando los Métodos Taguchi®*", *Ediciones Díaz de Santos*, Madrid.

Yavuz, I.H. and Satir, A., (1995) "A Kanban-based simulation study of a mixed model just-in-time manufacturing line", *International Journal of Production Research*, 33(4), 1027-1048.

Zipkin, P., (1989) "A kanban-like production control system: analysis of simple models", Research Working Paper No. 89-1, Graduate School of Business, Columbia University, New York, NY 10027.