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A method to enhance volume flexibility in JIT production control

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Abstract

The issue of strategic flexibility in manufacturing is reviewed to establish the links between output flexibilities and resource level characteristics. Through these links, and considering a JIT environment, the need for flexible Kanban determination is then recognised with respect to demand fluctuations in the marketplace. This is also confirmed through a review of the related literature. Based on this recognition, a method is proposed, using an integer linear programming technique, to flexibly determine the number of Kanbans for each stage of a JIT production system, minimising total inventory cost for a given planning horizon. The effectiveness of the proposed method is then examined and compared with the results for the conventional method of fixed Kanban determination. The comparison proved a cost advantage for the proposed method over the conventional method in fluctuating demand situations while the cost advantage increases with increase in demand fluctuations. The proposed method incorporates practical limitations for changing the number of Kanbans in any stage of production. This aspect of the method is also discussed in the paper.

Keywords: Strategic flexibility; Volume flexibility; Just-in-time; Production control; Flexible Kanban

1. Introduction

In the following sections, a review of manufacturing strategic flexibility establishes the links between output flexibilities and resource level characteristics. This, in particular, is followed by a study of the links between manufacturing output volume flexibility and production control characteristics for a JIT production environment. Our study highlights the need to enhance the flexibility of the Kanban method, which is a main tool for production control in a JIT system. Based on this recognition, a method is proposed to flexibly determine the number of Kanbans for each stage of a JIT production system, minimising total inventory cost for a given planning horizon. The effectiveness of the proposed method is then examined and the results are discussed indicating cost advantages for this method.

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2. A review of manufacturing strategic flexibility

The core content of a manufacturing strategy includes cost, quality, delivery dependability and flexibility, while the increasing competitive potential of flexibility has been widely recognised (Beach et al. (2000), Collins and Schmenner (1993), Gerwin (1993) and Gupta and Somers (1992)). Further, some authors discuss 'strategically flexible production' as an evolving paradigm and/or proclaim flexibility as the 'next competitive battle' (Spina (1998) and Spina et al. (1996)).

Manufacturing flexibility is recognised to be a multidimensional concept (e.g. D'Souza and Williams (2000), Gerwin (1993) and Slack (1987)). For instance, Gerwin's taxonomy consists of seven dimensions: volume flexibility, materials flexibility, mix flexibility, modification flexibility, changeover flexibility, rerouting flexibility and flexibility responsiveness. Alternatively, Slack suggests that flexibility can be considered in four areas: product change; product mix; volume and delivery.

Volume flexibility, which is of the main concern in this paper, is defined in short as "the ability to change the volume of output of a manufacturing process in accordance to customer orders". This is an important flexibility dimension, since orders exactly reflect actual demand fluctuations.

Operationalisation of manufacturing strategy is a major concern as discussed by Nilsson and Nordhal (1995a,b) and Rho et al. (2001) and many other authors. Nilsson and Nordhal discuss flexibility in terms of the elements in the chain of strategy-manufacturing strategy-resources. Reviewing previously developed flexibility related frameworks; they find them helpful at the manufacturing strategy level but not giving sufficient guidance as how to make the frameworks operational in manufacturing. They propose a framework which shows how to obtain consistency from manufacturing strategy to the resource characteristics in the production system. This framework considers an input-transformation-output (ITO) model, supplemented with the flow of information; taking into account requested and replied flexibilities at the levels of marketplace, manufacturing processes and suppliers.

3. Volume flexibility in JIT production control

3.1. Relationship between volume flexibility and production control characteristics in a JIT system

The just-in-time production approach (JIT) aims to produce defect free goods in the required amount at the right time mainly through eliminating wastes, improving capabilities and establishing a continuous flow of production (Monden (1993)). This system was first introduced in the 1970s in Japan. Latterly, the desire to achieve manufacturing excellence has been the driving force for its implementation in many manufacturing companies all over the world. For the review of literature on JIT and its applications we may refer to Hallihan et al. (1997), Keller and Kazazi (1993), Cheng and Musaphir (1993) and Berkley (1992).

We use Nilsson's Framework to link flexibility required at the marketplace to the characteristics of production control at a single process level in a JIT system (Fig. 1). Steps for utilising this framework are

Step 1—Recognition of the gap in output flexibility,
Step 2—Linking output flexibility to system characteristics,
Step 3—Linking system characteristics to resource characteristics,
Step 4—Linking system characteristics to input flexibilities.

Having recognised the gap between market requirements and output flexibility in Step1, relationship between required output flexibility and system characteristics has to be established in Step 2. Considering volume flexibility, a sample result for this step is given in Table 1, in which, improvement directions are identified. Assuming a JIT based production system, however, effective supports from the system are expected for these specified enhancements (i.e. improvements regarding production flow, production control, lead time and batch size).

A JIT production system is composed of a chain of processes, each process responding to the demands occurring in its downstream process. Therefore, as shown in Fig. 1, Nilsson's framework can be extended to

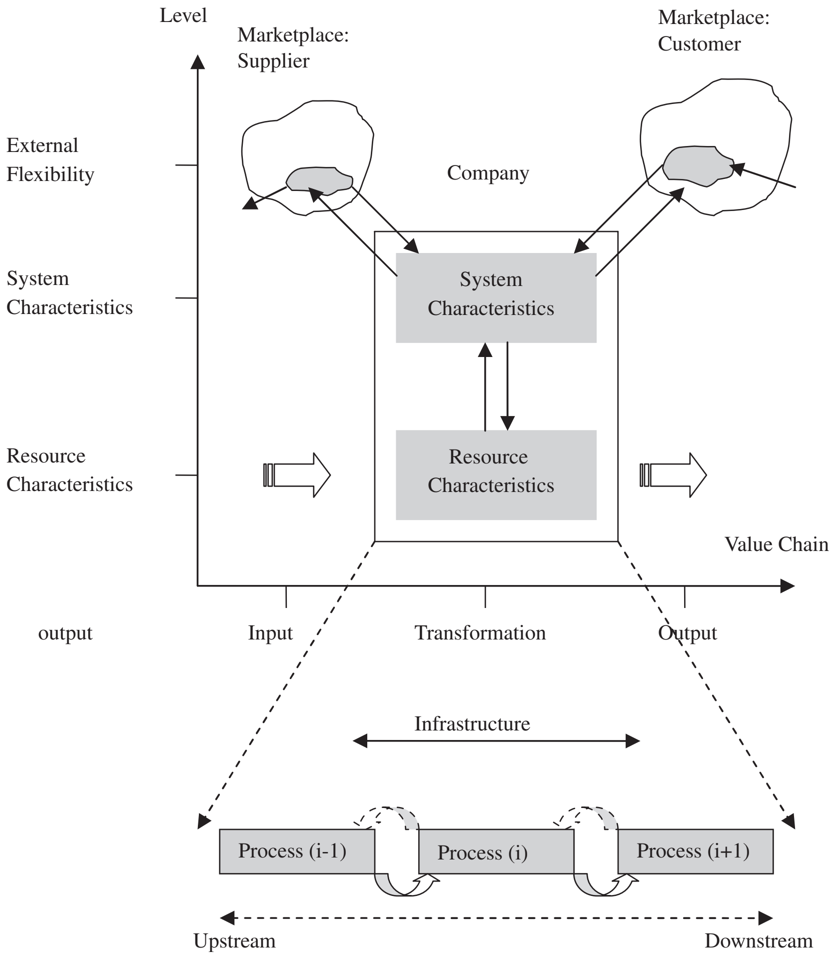

Fig. 1. Considering Nilsson's Framework for a JIT system.

Table 1
The relationship between output flexibilities and system characteristics

Output flexibility → system characteristics ↓	Volume flexibility	Mix flexibility	Changeover flexibility	…
Capacity	?	…	…	…
Production flow	Improve layout/flow of work	…	…	…
Production control	Improve control system capability	…	…	…
Lead time	Reduce lead time	…	…	…
Batch size	Reduce batch size	…	…	…
…	…	…	…	…

include these chains of processes. Table 2 represents the kind of relationship between system characteristics and resource characteristics for a single process also indicating improvement directions.

Having recognised related improvement areas, the aim is to "improve Kanban flexibility". In the following sections firstly a brief review of related aspects of Kanban method is given. Then, a method to improve Kanban flexibility is proposed and finally the proposed method is examined and evaluated.

Table 2
The relationship between 'volume flexibility' and resource characteristics

[Volume flexibility] → [Resource characteristics] ↓	Improve production flow	Improve production control	Reduce lead time	Reduce batch size	…
Process: Capacity	–	–	?	?	…
= : Layout	Improve layout	?	?	?	…
= : Setup times	Reduce setup time	?	Reduce setup time	Reduce setup time	…
= : Operator skills	?	–	?	More training	…
Production control	Improve control system	Improve Kanban flexibility	Reduce WIP	Reduce container capacity	…
Improvement activities (Kaizen), …	Improve production flow	Improve process flexibility	Reduce lead time	Reduce batch size	…

Marks used in this table: ? = needs further evaluation, – = not of primary relevance, … = not considered in this study.

3.2. A review of Kanban system literature

Issues such as the determination of the number of Kanbans, determination of Kanban operational parameters and the scheduling of Kanbans have been a centre of attention in Kanban system research. Below we refer to some major works in this regard.

Erhun et al. (2003) propose an analytical model to simultaneously determine the withdrawal cycle length and the number and the size of kanbans in a multi-item, multi-stage, multi-period, capacitated and periodic review kanban system. Akturk and Turkcan (2003), study the interaction of design and operational parameters in periodic review Kanban systems. Hemamalini and Rajendran (2000a,b) suggest a Simulated Annealing based solution for a Kanban-controlled flowshop. Their solution consists of two parts. The first part uses a recursive equation for time-tabling of containers. In the second part; with the objective of minimising the weighted sum of flowtime, tardiness and earliness of containers; they determine the allocation of the Kanbans for the given part-types. Philipoom et al. (1996) present a solution to multiple-level capacitated resource problem of determining container sizes, number of Kanbans and product sequence in a JIT production system. Dealing with deterministic demand, the operational objective for this work is to minimise sum of the inventory and set-up costs.

Originally, the JIT system was designed for a kind of environment which enjoys a good level of certainty. Therefore, the majority of the existing analytical solutions for the Kanban number determination are merely considering constant variables, i.e. dealing with fixed Kanban determination (e.g. Askin et al. (1993), Wang and Wang (1990), Bitran and Chang (1987)). This issue has also been discussed by Gupta et al. (1999), Savsar (1997), Chaturvedi and Golhar (1992) and some other researchers. However, as reviewed by Gupta (1999), Hallihan et al. (1997) and Keller and Kazazi (1993) relatively less attention has been paid for the flexible determination of the number of kanbans. Among those methods addressing Kanban flexibility aspects are: Markham et al. (2000)—kanban setting using AI and Neural networks, Gupta (1999)—Flexible kanban adjustment using simulation modelling, Moeeni et al. (1997)—proposing a kanban system design methodology, and Liberopoulos and Dallery (1995)—proposing a generalised kanban control for a single-stage situation. Further, Zäpfel (1998) suggests customer-order-driven production concept to economically respond to demand uncertainty and Rees et al. (1987) consider dynamically adjusting the number of Kanbans using estimated values of leadtime. The concept of dynamic Kanban control has also been considered in some more recent research works. For instance, we may refer to Takahashi et al. (2004) and Framinan et al. (2005).

Due to high demand fluctuations in recent marketplace a better level of flexibility is required from JIT production control. However, regarding Kanban flexibility, despite considerable results from previous research works, a lack of sufficient practicality can be concluded. This is mainly due to each work merely concentrating on a particular aspect of the kanban system and less practicality of some of the proposed methods.

In the present paper, having linked volume flexibility required at the market level to the flexibility required at the production control level in a JIT system, we propose an Integer Linear Programming method to flexibly determine the number of Kanbans minimising the inventory cost.

4. The proposed model for flexible Kanban determination

4.1. Overall description of the proposed model

In this paper we consider a JIT based production system composed of 'I' stages, serially connected producing a single final product. Each stage, as shown in Fig. 2 consists of an output (finished product) buffer, a manufacturing process, and a buffer for each input raw material. Co-ordination between different stages is achieved using a kanban method.

Two kinds of kanban are considered, which are: 'production kanban' and 'withdrawal kanban'. Production kanbans are attached to the buffer stock at the inventory point after each production process. This kanban, when the product or part is withdrawn by the downstream stage, is removed and then used for production-ordering and the movement of raw materials or parts to the production process. When the part is used for production, the withdrawal kanban attached to the part (or container) is removed and used for the withdrawal of the part to the inventory point.

We assume orders for the final product as well as withdrawals from any stage to follow a fixed interval discipline. We also assume that finished products delivery from final stage and withdrawal of raw material at any stage of production is carried out right before the start of each production period.

Our objective is to provide the kanban control system with the capability for volume flexibility while minimising total inventory cost for a given planning horizon. Assuming those external demands that cannot be immediately satisfied to be back-ordered, we consider total inventory cost composed of inventory carrying cost and backlog cost, but we do not include setup cost for this method.

An Integer linear programming model (referred to as Method 2) has been developed which determines the number of kanbans for each stage of production at each period independently, minimising total inventory cost. This method of flexible kanban determination will be explained in a following section. To establish a comparison base for the evaluation of the effectiveness of the proposed method, the traditionally used fixed kanban method has also been modelled for the same production system. This method (referred to as 'Method 1') is explained below.

4.2. Method 1—A linear programming model for fixed Kanban determination

Considering the model described in the previous section, we use an 'integer linear programming method' to calculate the number of kanban for each stage, aiming to minimise total inventory cost for a given planning

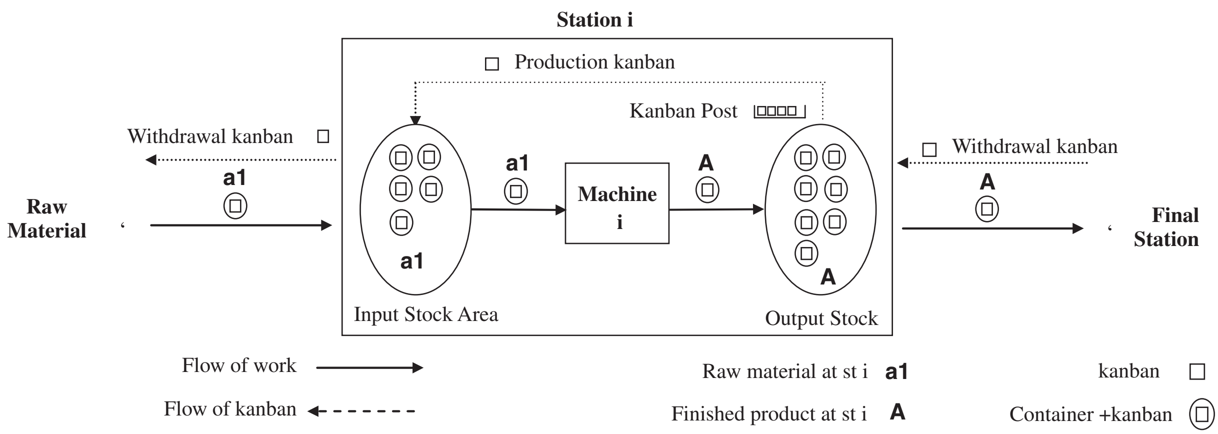

Fig. 2. A single stage of the production system.

Table 3
Parameters and variables used in Method 1

Parameters	Description
I	Production stages
T	Planning horizon (consisting of production periods)
CH_i	Holding cost for unit of inventory per production period at stage 'i'
CS_i	Shortage cost (per inventory unit)
B_i	Production capacity available at stage 'i' at each period
a_i	Capacity required at stage 'i' for the production of one unit of inventory
r_i	Units of the product at stage 'i' required by unit of product at stage '$i+1$'
$U_{i,0}$	Initial inventory at stage 'i'
D_t	Demand for final product (at stage I) at period 't'
Variables	Description
$X_{i,t}$	Production quantity at stage 'i' at period 't'
K_i	Number of Kanbnas allocated to stage 'i'
$U_{i,t}$	Number of Kanbans attached to the containers at stage 'i' at the end of period 't'
$U^{+}_{i,t}$	Positive inventory at stage 'i' at the end of period 't'
$U^{-}_{i,t}$	Negative inventory at stage 'i' at the end of period 't'
$RI_{i,t}$	Units of product required at stage 'i' at period 't'
$J2$–$J6$	Set of 0 and 1 variables
M	A big number

horizon. In this method the number of kanbans for each stage remains fixed within each planning horizon, while it can vary between different planning horizons. For the purpose of simplicity, container capacity for each product at any stage has been considered as the inventory unit for that item. Table 3 specifies the parameters and the variables for this method.

Based on the optimisation criteria, the objective function is

$$\min \quad Z = \sum_{t=1}^{T}\sum_{i=1}^{I} \mathrm{CH}_i U^{+}_{i,t} + \sum_{t=1}^{T}\sum_{i=1}^{I} \mathrm{CS}_i U^{-}_{i,t} \tag{1}$$

Subject to:

$$RI_{i,t} = r_i X_{i+1,t}, \quad t = 1,\ldots,T, \;\; i = 1,\ldots,I-1 \tag{2}$$

$$RI_{I,t} = D_t, \quad t = 1,\ldots,T \tag{3}$$

Inventory consumption at each station for each period.

$$U_{i,1} = U_{i,0} + X_{i,1} - RI_{i,1}, \quad i = 1,\ldots,I \tag{4}$$

$$U_{i,t} = U_{i,t-1} + X_{i,t} - RI_{i,t}, \quad t = 2,\ldots,T, i = 1,\ldots,I \tag{5}$$

Inventory balance relations.

$$K_i \geqslant U_{i,0}, \quad i = 1,\ldots,I \tag{6}$$

Relation between the number of Kanbans and the initial inventory.

$$X_{i,t} \leqslant K_i, \quad t = 1,\ldots,T, \;\; i = 1,\ldots,I \tag{7}$$

$$X_{i,1} \leqslant K_i - U_{i,0}, \quad i = 1,\ldots,I \tag{8}$$

$$X_{i,t} \leqslant K_i - U_{i,t-1}, \quad t = 2,\ldots T, \;\; i = 1,\ldots,I \tag{9}$$

Relations between the number of kanbans and the production quantity at each stage of each period.

$$r_{i-1}X_{i,1} \leqslant U_{i-1,0}, \quad i = 2, \ldots, I \tag{10}$$

$$r_{i-1}X_{i,t} \geqslant U_{i-1,t-1}, \quad t = 2, \ldots, T, \;\; i = 2, \ldots, I \tag{11}$$

Relations between production quantity at each station and the end of the period inventory at the preceding stage.

$$a_i X_{i,t} \leqslant B_i \quad t = 1, \ldots, T, \;\; i = 1, \ldots, I \tag{12}$$

Relation between production quantity and total capacity of the station.

$$X_{i,1} - K_i + U_{i,0} \geqslant M(J2_i - 1), \quad i = 1, \ldots, I \tag{8$'$}$$

$$X_{i,t} - K_i + U_{i,t-1} \geqslant M(J3_{i,t} - 1), \quad t = 2, \ldots, T, i = 1, \ldots, I \tag{9$'$}$$

Relations between the number of kanbans and the poduction quantity of each stage for each period.

$$r_{i-1}X_{i,1} - U_{i-1,0} \geqslant M(J4_i - 1), \quad i = 2, \ldots, I \tag{10$'$}$$

$$r_{i-1}X_{i,1} - U_{i-1,t-1} \geqslant M(J5_{i,t} - 1), \quad t = 2, \ldots, T, \quad i = 2, \ldots, I \tag{11$'$}$$

Relations between production quantity at each station and the end of the period inventory at the preceding stage.

$$a_i X_{i,t} - B_i \geqslant M(J6_{i,t} - 1), \quad t = 1 \ldots, T, \;\; i = 1, \ldots, I \tag{12$'$}$$

Relation between production quantity and total capacity of the station.

$$J2_i + J4_i + J6_{i,1} = 1, \quad i = 2, \ldots, I \tag{13}$$

$$J3_{i,t} + J5_{i.t} + J6_{i,t} = 1, \quad t = 2, \ldots, T, \;\; i = 2, \ldots, I \tag{14}$$

$$J2_1 + J6_{1,1} = 1 \tag{15}$$

$$J3_{1,t} + J6_{1,t} = 1, \quad t = 2, \ldots, T \tag{16}$$

Relations between "0 and 1" variables.

$$U_{i,t} = U^{+}_{I,t} - U^{-}_{i,t}, \quad t = 1, \ldots, T, \quad i = 1, \ldots, I \tag{17}$$

Positive or negative situations of the inventory.

Variables limitations:

$$\begin{aligned} &X_{i,t}, U^{+}_{i,t}, U^{-}_{i,t} \geqslant 0, \quad U_{i,t} : UNRESTRICTED \quad t = 1, \ldots, T, \quad i = 1, \ldots, I - 1. \\ &K_i : INTEGER \quad i = 1, \ldots, I - 1. \\ &J2_i, J3_{i,t}, J4_i, J5_{i,t}, J6_{i,t} : 0 \quad \text{or} \quad 1 \quad t = 1, \ldots, T, \quad i = 1, \ldots, I. \end{aligned} \tag{18}$$

Table 4
Other parameters and variables used in Method 2

Parameters	Description
$K_{i,0}$	Initial number of Kanban (carried from previous period or determined by Method 1)
α	Ratio of variation of number of Kanban with respect to $K_{i,0}$
CK	The cost associated with the increase or decrease of one Kanban at each station
Variables	Description
$K_{i,t}$	Number of Kanbans assigned to stage 'i' at period 't'
$K^+_{i,t}$	Number of Kanbans increased at stage 'i' from period 't–1' to period 't'
$K^-_{i,t}$	Number of Kanbans decreased at stage 'i' from period 't–1' to period 't'

Relations 1 and 2 are used to calculate the consumption of products at each stage for each period. Inventory situations are calculated using relations 4 and 5 whereas relations 6 through 9 introduce constraints in kanban number determination.

Further, we note that

Production quantity at each stage for each period = MIN {A, B, C}, where
A = number of detached Kanbans available at the start of each period,
B = equivalent quantity of raw material available at the start of each period,
C = production capacity available at each period.

4.3. Method 2—A linear programming model for flexible Kanban determination

In this method, the number of kanbans for each stage can vary between production periods at any given planning horizon. A linear programming method has been developed which determines the number of kanbans for each stage, through minimising total inventory cost for the planning horizon. Using the parameters and variables defined for Method 1, additional definitions for Method 2 are given in Table 4.

The objective function is

$$\min \ Z = \sum_{t=1}^{T}\sum_{i=1}^{I} \mathrm{CH}_i U^+_{i,t} + \sum_{t=1}^{T}\sum_{i=1}^{I} \mathrm{CS}_i U^-_{i,t} + \sum_{t=1}^{T}\sum_{i=1}^{I} \mathrm{CK}(K^+_{i,t} + K^-_{i,t}) \tag{1}$$

This is subject to those relations given for Method 1 together with the following additional relations:

$$K_{i,t} = K_{i,t-1} + K^+_{i,t} - K^-_{i,t}, \quad t = 2, ..., T, \ \ i = 1, ..., I, \tag{17}$$

$$K_{i,1} = K_{i,0} + K^+_{i,1} - K^-_{i,1} \quad i = 1, \ldots, I, \tag{18}$$

$$K_{i,t} \leqslant K_{i,0} + \alpha K_{i,0}, \quad t = 1, \ldots, T, \quad i = 1, \ldots, I, \tag{19}$$

$$K_{i,t} \geqslant K_{i,0} - \alpha K_{i,0}, \quad t = 1, \ldots, T, \quad i = 1, \ldots, I. \tag{20}$$

Further variable limitations are

$$K^+_{i,t}, K^-_{i,t} \geqslant 0, \quad t = 1, \ldots, T, \quad i = 1, \ldots, I-1,$$
$$K_{i,t}: \ \ INTEGER, \quad i = 1, \ldots, I-1.$$

In this method, $K^+_{i,t}$ and $K^-_{i,t}$ represent the increase and decrease in the number of Kanbans for each stage between any two successive periods. A cost factor (CK) has been assigned for the change in the number of Kanbans as this can cause a setup or a change in resource allocation. Since there are usually practical

Table 5
Results for numerical example using Method 2

		Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Stage 1		K = 26	K = 27	K = 27	K = 21	K = 21	K = 21
	Ko = 26	X = 10	X = 12	X = 15	X = 6	X = 15	X = 6
	Uo = 16	RI = 11	RI = 15	RI = 12	RI = 15	RI = 6	RI = 15
		U = 15	U = 12	U = 15	U = 6	U = 15	U = 6
Stage 2		K = 54	K = 54	K = 54	K = 54	K = 54	K = 54
	Ko = 56	X = 22	X = 30	X = 24	X = 30	X = 12	X = 30
	Uo = 32	RI = 32	RI = 22	RI = 30	RI = 24	RI = 30	RI = 12
		U = 22	U = 30	U = 24	U = 30	U = 12	U = 30
Stage 3		K = 42	K = 42	K = 42	K = 42	K = 42	K = 42
	Ko = 42	X = 16	X = 11	X = 15	X = 12	X = 15	X = 6
	Uo = 20	RI = 9	RI = 10	RI = 16	RI = 21	RI = 18	RI = 15
		U = 27	U = 28	U = 27	U = 18	U = 15	U = 6
Stage 4		K = 23	K = 23	K = 23	K = 22	K = 22	K = 22
	Ko = 22	X = 9	X = 10	X = 16	X = 21	X = 18	X = 15
	Uo = 14	RI = 10	RI = 16	RI = 22	RI = 22	RI = 18	RI = 15
		U = 13	U = 7	U = 1	U = 0	U = 0	U = 0
		D = 10	D = 16	D = 22	D = 22	D = 18	D = 15

Table 6
Average total cost for each set of examples using Methods 1 and 2

Demand pattern	Av. total cost—Method 1	Av. total cost—Method 2	% cost reduction
N (15.3)	1188.6	1137.5	4.3
N (15.6)	1499.4	1425.7	4.9
N (15.9)	1580.2	1490.4	5.7

limitations to a change in the number of Kanbans, this has been incorporated in the method by the use of the 'α' factor. This factor also represents the level of flexibility in shopfloor operations. To illustrate more details for this method, a numerical example is given below.

4.4. Numerical example

We consider a production system consisting of 4 stages with the input parameter values as given below.

$I = 4$	$\mathrm{CK} = 1$	$K_{i,0} = 26, 26, 56, 42, 22$
$T = 6$	$B_i = 480, 480, 480, 480$	$\alpha = 0.2$
$\mathrm{CH}_i = 2, 1.5, 3.5, 3.7$	$a_i = 9, 10, 18, 22$	$U_{i,0} = 16, 32, 20, 14$
$\mathrm{CS}_i = 2, 2, 2, 12$	$r_i = 0.5, 2, 1, 1$	$D_t = 10, 16, 22, 22, 18, 15$

Using Method 2 the results are summarised in Table 5. As it is shown in this table the number of Kanbans for each stage can be different for the production periods. For instance, considering stage 1, the number of Kanbans for periods 1 through 6 are 26, 27, 27, 21, 21, 21, respectively. The table also includes some other results such as production and consumption quantities and the ending inventory for each stage at different periods.

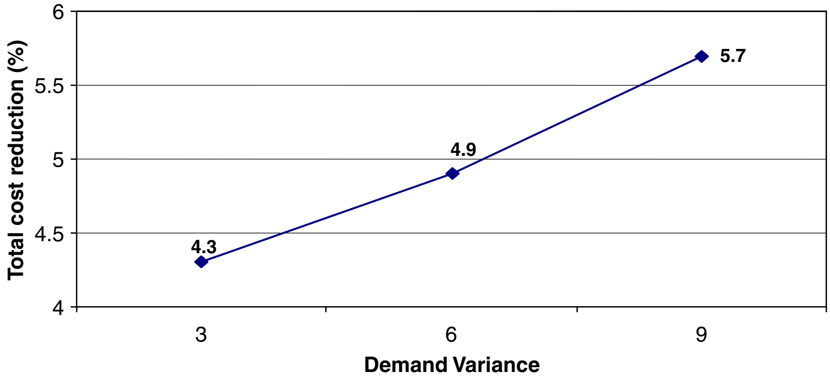

Fig. 3. Cost reduction (%) for Method 2 at different demand variance situations.

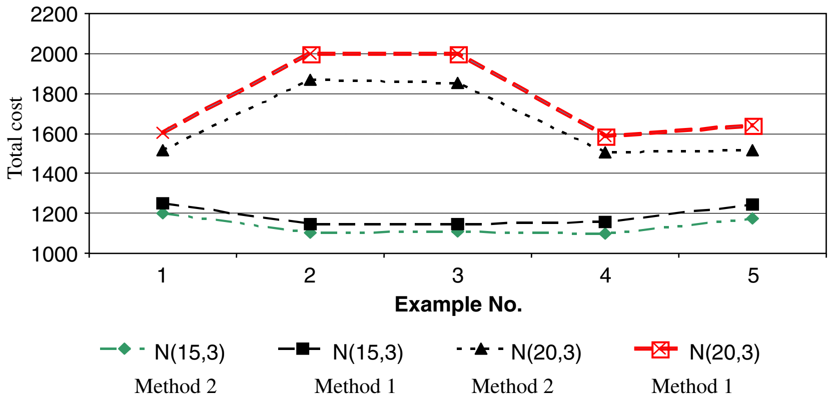

Fig. 4. Effect of demand mean variation on total cost.

5. Examining the effectiveness of the proposed method

We consider the effects of both the variance and the mean of demand on the effectiveness of the proposed method.

5.1. Effect of demand variance on the effectiveness of the proposed method

Methods 1 and 2 have both been used for a set of 5 examples, each with different initial state values, and considering 3 demand situations. Each example consists of 5 production stages and the planning horizon includes 8 periods. Demand (N) is assumed to follow a normal distribution with a mean of 15; while the variance is considered to be 3, 6 or 9 for the 1st, 2nd and 3rd set of examples respectively.

A comparison of the results indicated superiority of Method 2 in all cases with respect to total inventory cost. The average total cost for each set of examples using both methods as well as the cost reduction resulting from Method 2, are summarised in Table 6 and also demonstrated in Fig. 3.

5.2. Effect of demand mean variation on the effectiveness of the proposed method

The same set of 5 examples were used with demand patterns of $N(15,3)$ and $N(20,3)$. Fig. 4 compares total costs resulting from the use of Methods 1 and 2 for these cases.

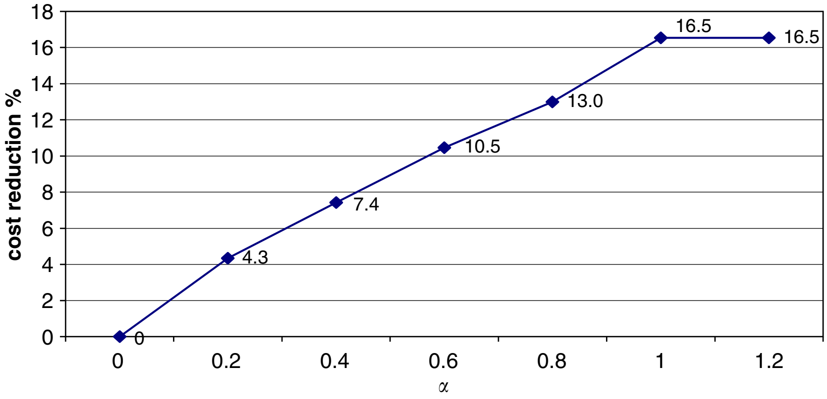

Fig. 5. Reduction in total cost for Method 2 for different values of 'α'.

Since any increase in the demand mean causes an increase in the inventory level (i.e. an increase in kanban number), this results in a higher total inventory cost. However, as shown in Fig. 4, in both situations the total costs were lower for Method 2 compared to Method 1. Comparing the two methods for the above examples, the percentage of cost reductions which resulted from Method 2 are 6.4 and 4.3 for demand patterns $N(20, 3)$ and $N(15, 3)$, respectively.

5.3. Effect of the Kanban variation coefficient

Here we consider the effect of the variation of the number of Kanbans on total inventory cost. We note that the acceptable rate of variation of the number of Kanban which is represented by 'α' is a decision factor which is determined on the basis of the flexibility of the production stage to meet demand variation. Therefore, any increase in this factor indicates better flexibility of the production stage. This factor, on the other hand, represents the level of flexibility required from upstream production stages. That is, any increase in the value of 'α' will decrease the degree of production levelling for upstream processes. Therefore, in practice, some limitations are expected to be imposed on this factor. To study the effect of this factor on the performance of our proposed method, we consider the previous set of 5 examples (with 5 stages and 8 periods), while the demand pattern is $N(15,3)$. These examples were considered in the previous section for $\alpha = 0.2$ only, but here we use different values of α (0.2, 0.4, 0.6, 0.8, 1.00 and 1.2) for the same example. Fig. 5 shows cost reductions resulting from Method 2 compared to Method 1, for different values for 'α'.

We can see an increase in the value of α results in a better cost reduction situation, and of course better flexibility. Therefore, as it is generally emphasised in JIT, there should be continuous effort to improve the capabilities of operations for better flexibility. It is also shown that there is no more cost reduction when α is increased from 1.00 to 1.2. This is due to an increase in shortages which indicates excessive imbalance between production and demand.

6. Conclusion

Manufacturing strategic flexibility has been recognised as a major competitive potential in the recent marketplace. Volume flexibility is an important dimension of manufacturing flexibility since orders vary in accordance with actual demand fluctuations. The link between volume flexibility at manufacturing output level and related characteristics required at process level have been studied in this paper. This study, considering a JIT production environment, led to the recognition of a need to improve Kanban method flexibility. This recognition of the need was also confirmed through a literature review in this respect.

Having presented a model of the Kanban method of production control, an 'integer linear programming method' (referred to as Method 2) was developed for flexible Kanban determination. The proposed method, flexibly determines the number of Kanbans for each stage of production at each period of the planning horizon minimising total inventory cost. Total inventory cost is defined to cover inventory holding and backlog costs as well as costs associated with any change in the number of Kanbans at each process.

The effectiveness of the proposed method was examined through some examples comparing their results with the results for a conventional fixed Kanban method which was also modelled using an integer LP method (referred to as Method 1). This comparison proved a cost advantage for the proposed method over the conventional method in fluctuating demand situations. The more fluctuation in demand the more cost advantage is expected for the proposed method.

One other important aspect of the proposed method is the incorporation of the Kanban variation factor (α) which reflects practical limitations for changing the number of Kanbans for each stage of production. For this factor, a value of zero represents no volume flexibility in the process and the result is a fixed Kanban situation. An increase in this value indicates a flexibility increase in the process itself as well as the Kanban method to control that specific process.

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