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# Overview of Kanban systems

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**Abstract.** The just-in-time (JIT) approach to manufacturing control with 'Kanbans' has received much attention in the last decade. The Kanban systems efficiently control repetitive manufacturing environments and offer simplicity. However, they are not suitable for non-repetitive manufacturing systems. The research approaches applied to Kanban systems include simulation, mathematical, and stochastic approaches, with the emphasis on analysing characteristics of Kanban systems, determining the optimal number of Kanbans, and comparing Kanban systems. In this paper, an overview of different Kanban systems, methodologies, and alternatives to the pure Kanban systems are discussed. The basic Toyota Kanban system is introduced. The recently developed methodologies for Kanban systems are surveyed. The Kanban approach is illustrated with the case studies. This paper offers a broad discussion of Kanban systems and classifies the previous studies. Several conclusions are drawn and suggestions for further research are given.

## 1. Introduction

The just-in-time (JIT) approach to control manufacturing systems with 'Kanbans' has received much attention in the last decade (Chase and Aquilano 1985, Huang *et al.* 1983, Hall 1983, Suzaki 1987, Krajewski *et al.* 1987, Shingo 1988). The idea of Kanban originated from US supermarkets (Ohno 1988, pp. 25–27), where customers get: (1) what is needed, (2) at the time it is needed, and (3) the amount needed. A supermarket manager maintains a certain amount of inventory on the shelves. The idea of tangible and touchable food items in a supermarket was applied by Taiichi Ohno in Toyota around 1953 to:

(1) reduce inventory and production cycle time;
(2) increase the speed of information exchange; and
(3) improve productivity.

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In the Kanban system, tangible objects, cards that contain information such as the job type, the quantity of parts to carry, and the Kanban type, have become crucial in production management. With the movement of the cards, information becomes tangible and easily understood.

The concept of 'push' systems has been used in industry for a long time. In a 'push' system, jobs are released to the first stage of manufacturing, and in turn this stage pushes the work in process to the succeeding stage and so on, until the final products are obtained. The Kanban system is known as a 'pull' system in the sense that the production of the current stage depends on the demand of the subsequent stages, i.e. the preceding stage must produce only the exact quantity withdrawn by the subsequent manufacturing stage. In this way, the Kanban system was created to indicate what is needed at each production stage, and to allow various stages to efficiently communicate with each other. The company's production plan is given only to the final assembly line. When parts or materials are withdrawn from the preceding stage, a chain of communication is established with each of the relevant preceding stages, and every stage automatically knows how much and when to produce the parts required. At each station, the information about the product name, code, volume, and so on, can be easily obtained from the Kanbans. Figure 1 illustrates the general Kanban system.

### 1.1. *Principles of implementation of Kanban systems*

The main principles for the implementation of Kanban systems are as follows (Hall 1983, p. 123; Ohno 1988, pp. 29–44; Singh and Falkenburg 1994):

(1) Level production (balance the schedule) in order to achieve low variability of the number of parts from one time period to the next.

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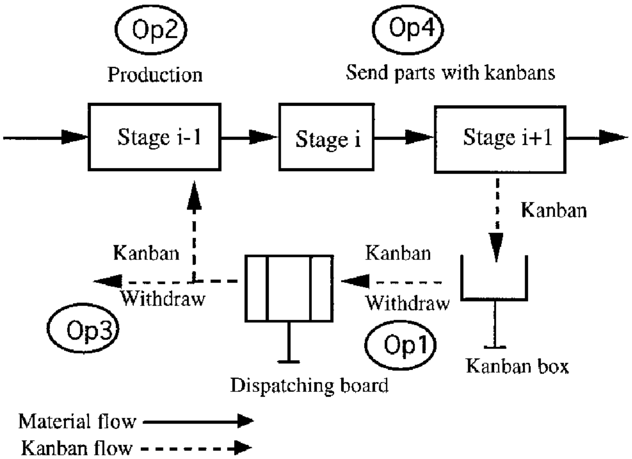


Figure 1. The general Kanban system. OP1: When demand from stage $i+1$ occurs, withdraw kanbans and place them on the dispatching board. OP2: Production activity initiates when kanban is placed on the dispatching board. OP3: Simultaneously, demand is sent to stage $i-1$ if the demand occurs at state i. OP4: Completed parts with kanbans are sent to stage $i+1$.

(2) Avoid complex information and hierarchical control systems on a factory floor.
(3) Do not withdraw parts without a Kanban.
(4) Withdraw only the parts needed at each stage.
(5) Do not send defective parts to the succeeding stages.
(6) Produce the exact quantity of parts withdrawn.

### 1.2. *Functions of Kanbans*

The key objective of a Kanban system is to deliver the material just-in-time to the manufacturing workstations, and to pass information to the preceding stage regarding what and how much to produce.

A Kanban fulfills the following functions:

(1) *Visibility function*
The information and material flow are combined together as Kanbans move with their parts (work-in-progress, WIP).

(2) *Production function*
The Kanban detached from the succeeding stage fulfills a production control function which indicates the time, quantity, and the part types to be produced.

(3) *Inventory function*
The number of Kanbans actually measures the amount of inventory. Hence, controlling the number of Kanbans is equivalent to controlling the amount of inventory; i.e. increasing (decreasing) the number of Kanbans corresponds to increasing (decreasing) the amount of inventory. Controlling the number of Kanbans is much simpler than controlling the amount of inventory itself.

### 1.3. *Kanbans*

According to their functions, Kanbans are classified into:

(1) Primary Kanban: travels from one stage to another among main manufacturing cells or production preparation areas. The primary Kanbans are two kinds, one of which is called 'withdrawal Kanban' (conveyor Kanban) that is carried when going from one stage to the preceding stage. The other one is called 'production Kanban' (Figure 2) and is used to order production of the portion withdrawn by the succeeding stage. These two kinds of Kanbans are always attached to the containers holding parts.
(2) Supply Kanban: travels from a warehouse or storage facility to a manufacturing facility (see Figure 3).
(3) Procurement Kanban: travels from outside of a company to the receiving area (see Figure 4).
(4) Subcontract Kanban: travels between subcontracting units.
(5) Auxiliary Kanban: may take the form of an express Kanban, emergency Kanban, or a Kanban for a specific application (Singh and Falkenburg 1994).

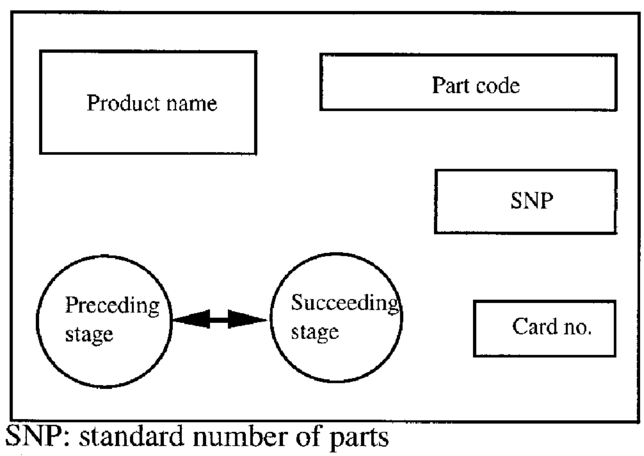


Figure 2. The production Kanban.

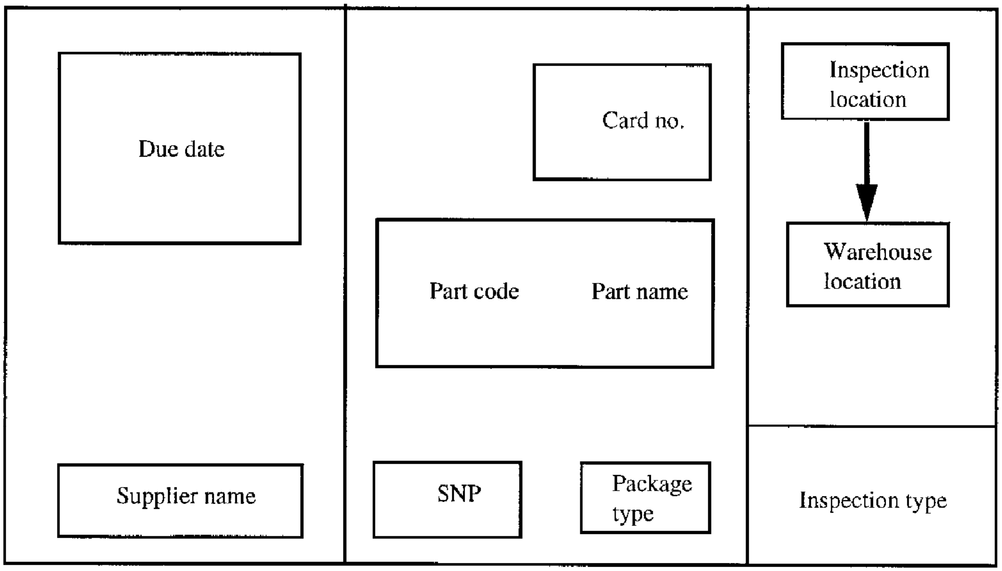


Figure 3. The supply Kanban.

### 1.4. *Auxiliary equipment*

(1) Kanban box: to collect Kanbans after they are withdrawn.
(2) Dispatching board: in which Kanbans from the succeeding stage are placed in order to display the production schedule.
(3) Kanban management account: an account to manage Kanbans.
(4) Supply management account: an account to manage the supply of raw materials.

### 1.5. *General description of Kanban operations*

For production stage $i$, when parts are processed and demand from its receiving stage $i+1$ occurs, the production Kanban is removed from a container and is placed on the dispatching board at stage $i$. The withdrawal Kanban from stage $i+1$ then replaces the production Kanban and the container. This container along with the withdrawal Kanban is then sent to stage $i+1$ for processing.

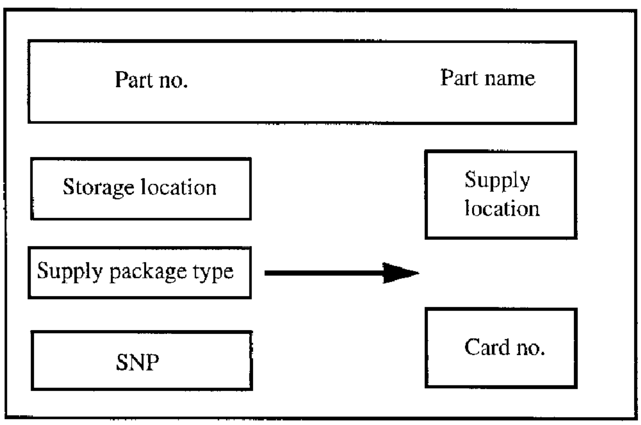


Figure 4. The procurement Kanban.

Meanwhile at stage $i$, the production activity takes place when a production Kanban and a container with the withdrawal Kanban are available. The withdrawal Kanban is then replaced by the production Kanban and sent back to stage $i-1$ to initiate production activity at stage $i-1$. This forms a cyclic production chain.

The Kanban pulls (withdraws) parts instead of pushing parts from one stage to another to meet the demand at each stage. The Kanban controls the move of product, and the number of Kanbans limits the flow of products (Shingo 1987). If no withdrawal is requested by the succeeding stage, the preceding stage will not produce at all, and hence no excess items are manufactured. Therefore, by the number of Kanbans (containers) circulating in a JIT system, non-stock-production (NSP) may be achieved.

### 1.6. *Kanban control*

Toyota considered its system of external and internal processes as connected with invisible conveyor lines (Kanbans). The information flow (Kanban flow) acts like an invisible conveyor through the entire production system and connects all the department

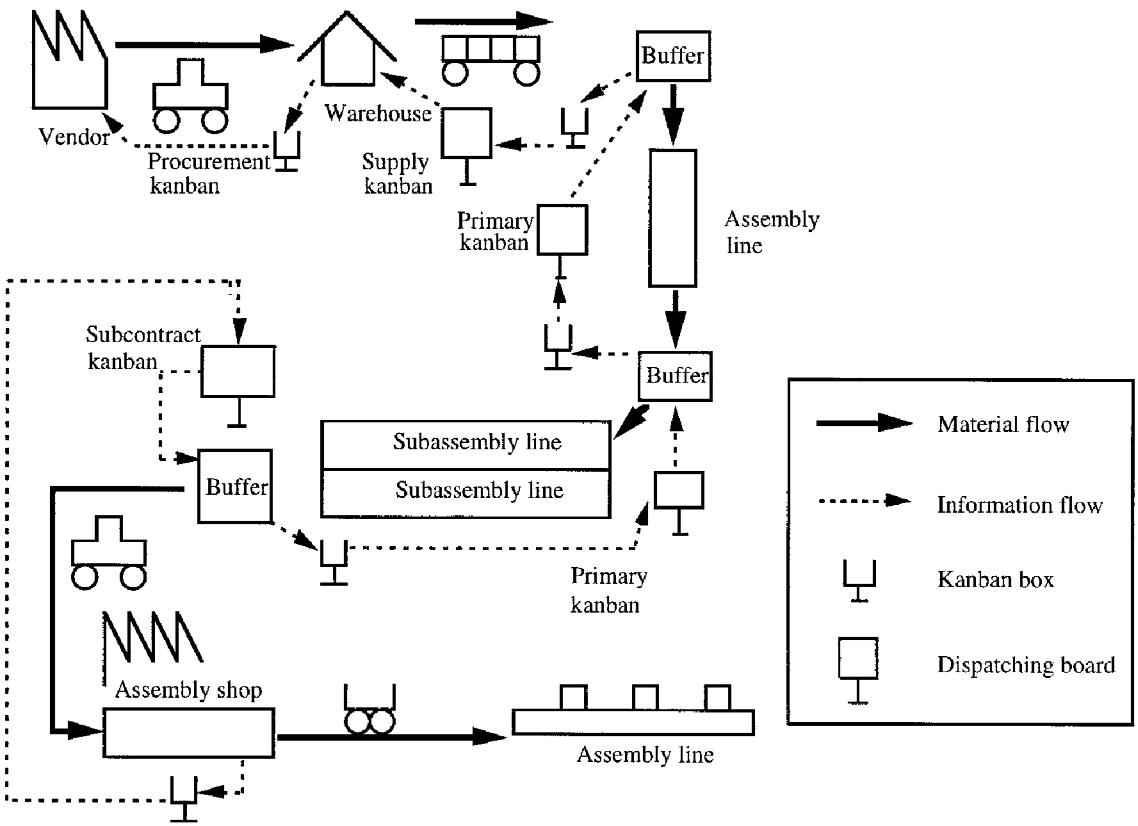


Figure 5. A general Kanban control system.

together. Figure 5 presents a general Kanban control system (Lu 1982, p. 540).

1.6.1. *The production line.* Due to different types of material handling systems, there are three types of control (Lu 1982, pp. 541–546):

(1) *Single Kanban system (using production Kanbans)*

The single Kanban (single-card) system uses production Kanbans only to block material-handling based on the part type. The production is blocked at each stage based on the total queue size (Figure 6). In a single-card system, the size of a station output buffer and part mix may vary. Multiple containers contain the batches to be produced, as long as the total number of full containers in the output buffer does not exceed the buffer output capacity. Note that the single-card system is in no way related to the hybrid push-pull-schedule-driven single-card system described by Schonberger (1982a).

The following conditions are essential for a proper functioning of the single Kanban system:

(a) small distance between any two subsequent stages;
(b) fast turnover of Kanbans;
(c) low WIP;
(d) small buffer space and fast turnover of WIP; and
(e) synchronization between the production rate and speed of material handling.

(2) *Dual Kanban system (using two Kanbans simultaneously)*

The dual Kanban system (two-card system) uses production and withdrawal Kanbans to implement both the station and material-handling blocking by part type. There is a buffer for WIP while transporting the finished parts from a preceding stage to its succeeding stage. The withdrawal Kanbans are presented in the buffer area (see Figure 7). The most common form of two-card Kanban production control is described in Sugimori *et al.* (1977), Monden (1983a, pp. 17–20), and Schonberger (1982a, pp. 221–224).

This system is appropriate for manufactures who are not prepared to adopt strict control rules to the buffer inventory. The following conditions are essential for the dual Kanban system:

(a) moderate distance between two stages;
(b) fast turnover of Kanbans;
(c) some WIP in a buffer is needed;
(d) external buffer to the production system; and

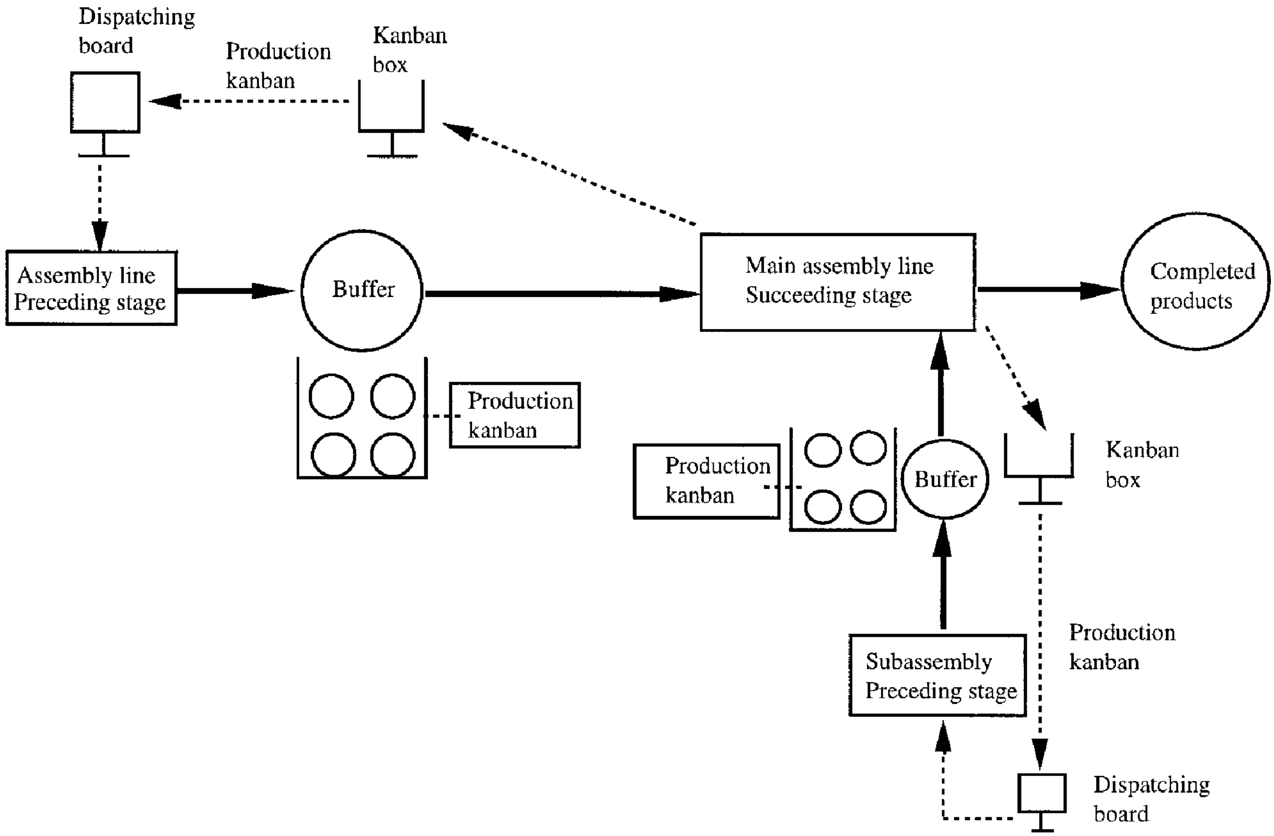


Figure 6. The single Kanban system.

(e) synchronization between the production rate and speed of material handling

(3) *Semi-dual Kanban system (changing production Kanbans and withdrawal Kanbans at intermediate stages)*

Figure 8 presents the semi-dual Kanban system. The semi-dual Kanban system has the following characteristics:

(a) large distance between two stages;
(b) slow turnover of Kanbans;
(c) large WIP is needed between subsequent stages;
(d) slow turnover of WIP;
(e) synchronization between the production rate and speed of material handling is not necessary.

Table 1 compares the three types of Kanban systems.

1.6.2. *The receiving area.* Based on different types of receiving, three types of Kanban operations are performed:

(1) receiving from a preceding stage in the same facility (see Figure 6);
(2) receiving from a storage (see Figure 9);
(3) receiving from a vendor (see Figure 10).

1.6.3. *The optimal number of Kanbans.* The number of Kanbans is determined based on the amount of inventory. It is important to have an accurate number of Kanbans so that the WIP is minimized and simultaneously the out-of-stock situation is avoided.

In the Toyota Kanban system:

number of Kanbans = (maximum daily production quantity) * (production waiting time + production processing time + withdraw lead time + safety factor)÷ standard number of parts (SPN)

*Remarks*

(a) The maximum daily production quantity is the maximum output based on the daily production plan. Note that the production quantity should not vary too much on a daily basis, which is one of the necessary conditions to implement the Kanban production concept.

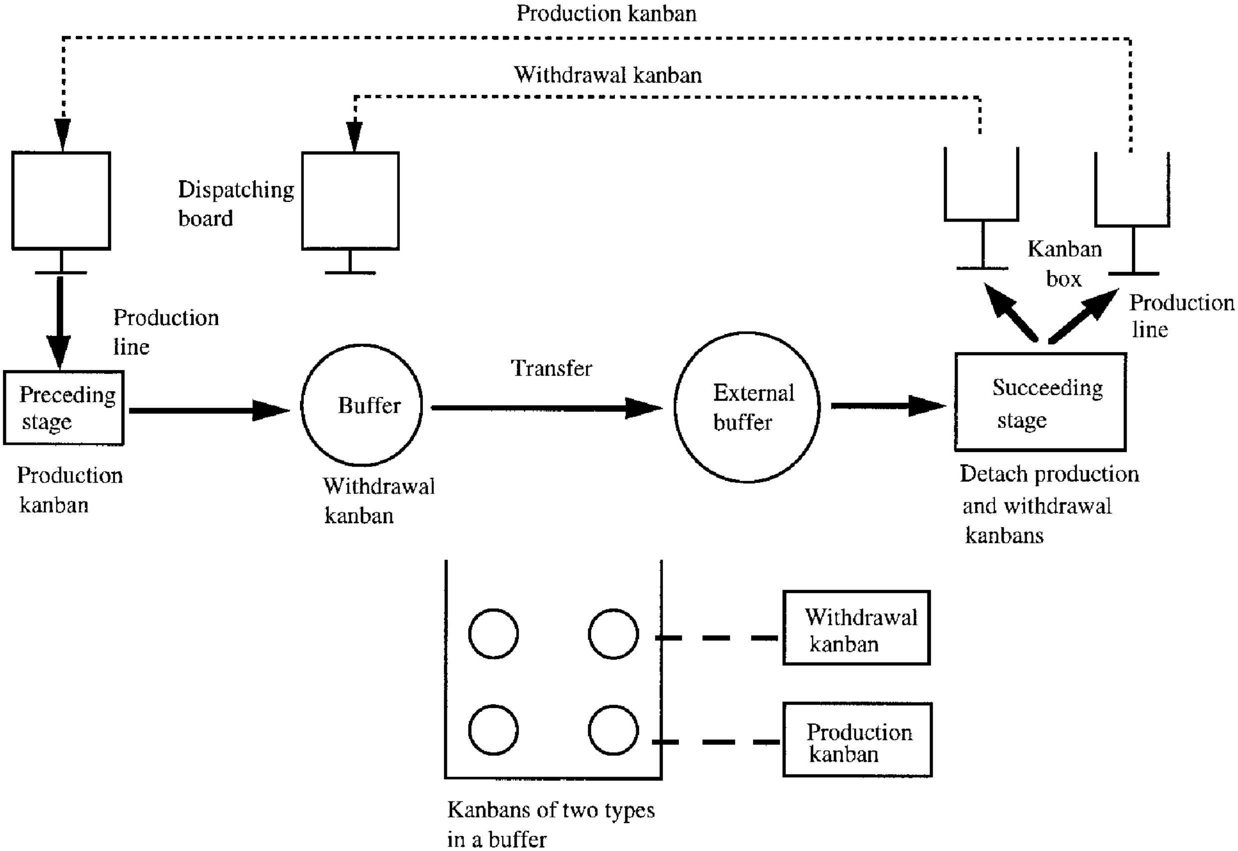


Figure 7. The dual Kanban system.

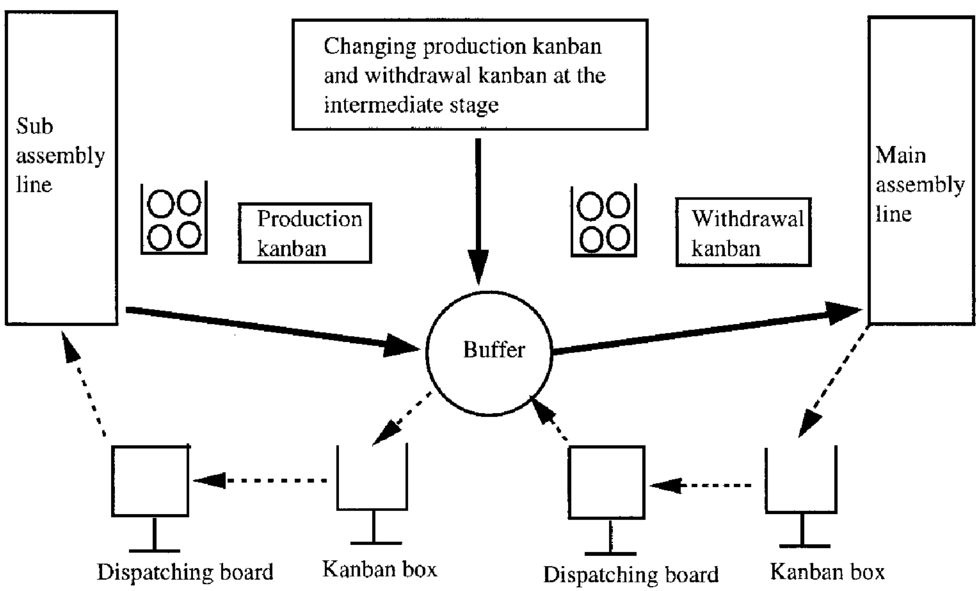


Figure 8. The semi-dual Kanban system.

Table 1. Comparison of the three types of Kanban systems.

| | SKS | DKS | SDKS |
|---|---|---|---|
| Distance between two stages | Small | Moderate | Large |
| WIP between two stages | Small | Small | Large |
| Turnover of Kanbans | Fast | Fast | Low |
| Turnover of WIP | Fast | Moderate | Slow |
| Synchronization of production and movement of WIP | Necessary | Not necessary | Necessary |

SKS: Single Kanban system.
DKS: Dual Kanban system.
SDKS: Semi-dual Kanban system.

(b) Production waiting time is the idle interval between two production commands (for example 0·5 day in Figure 11).
(c) Production processing time is the interval between receiving production command and completing the lot.
(d) Withdrawal lead time is the interval between withdrawing a Kanban from the preceding stage and issuing a production command.
(e) The safety factor is based on time unit, e.g. day. It allows avoidance of an interruption of the production line due to unexpected conditions.
(f) SNP represents the standard number of parts. A Kanban indicates the standard number of the parts.

The number of Kanbans between adjacent stations impacts the inventory level between these two stations. Several methods have been developed for determining the optimal number of Kanbans (see Section 2.3).

In Figure II, the cycle time of Kanbans (part {A, B, C}) = 0·1 + 0·5 + 0·5 + 0·2 + 0·1 + 0·1 = 1·5 (days). The number of Kanbans of part {A, B, C} = 1000 * 1·5/100 = 15 (Kanbans), where $Q_{max}$ = 1000 and SNP = 100.

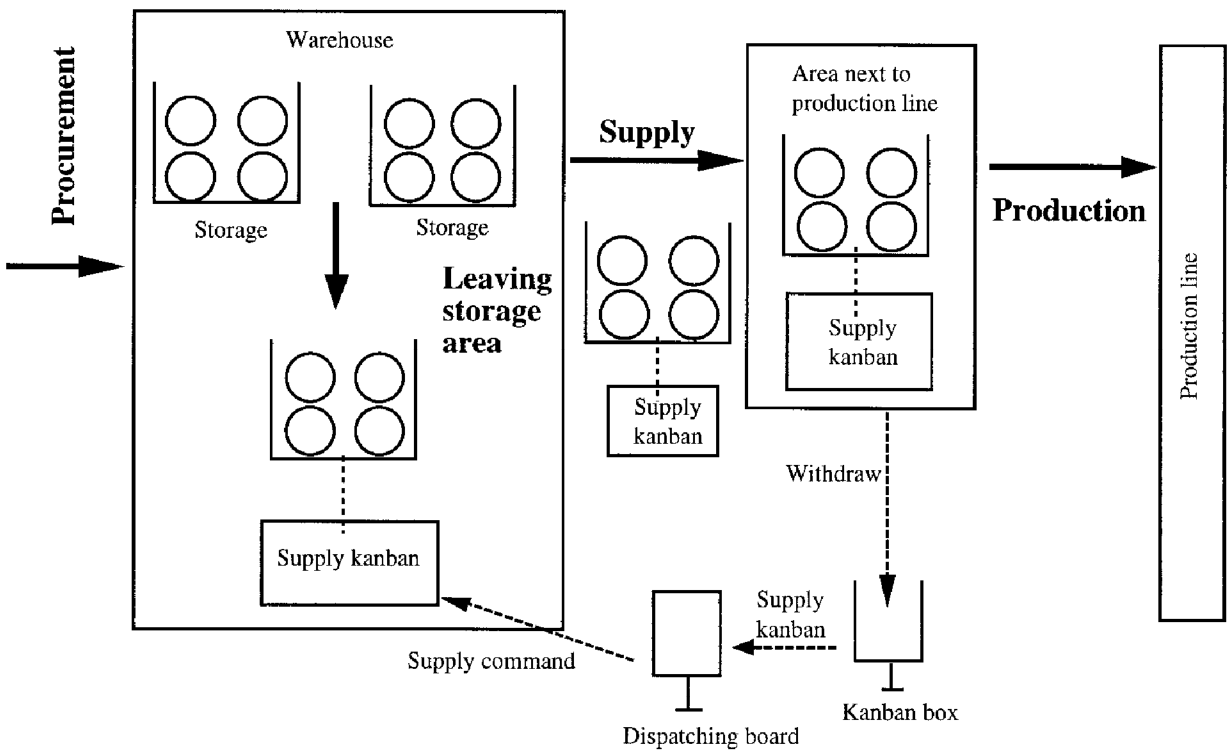


Figure 9. The Kanban system receiving parts from warehouses.

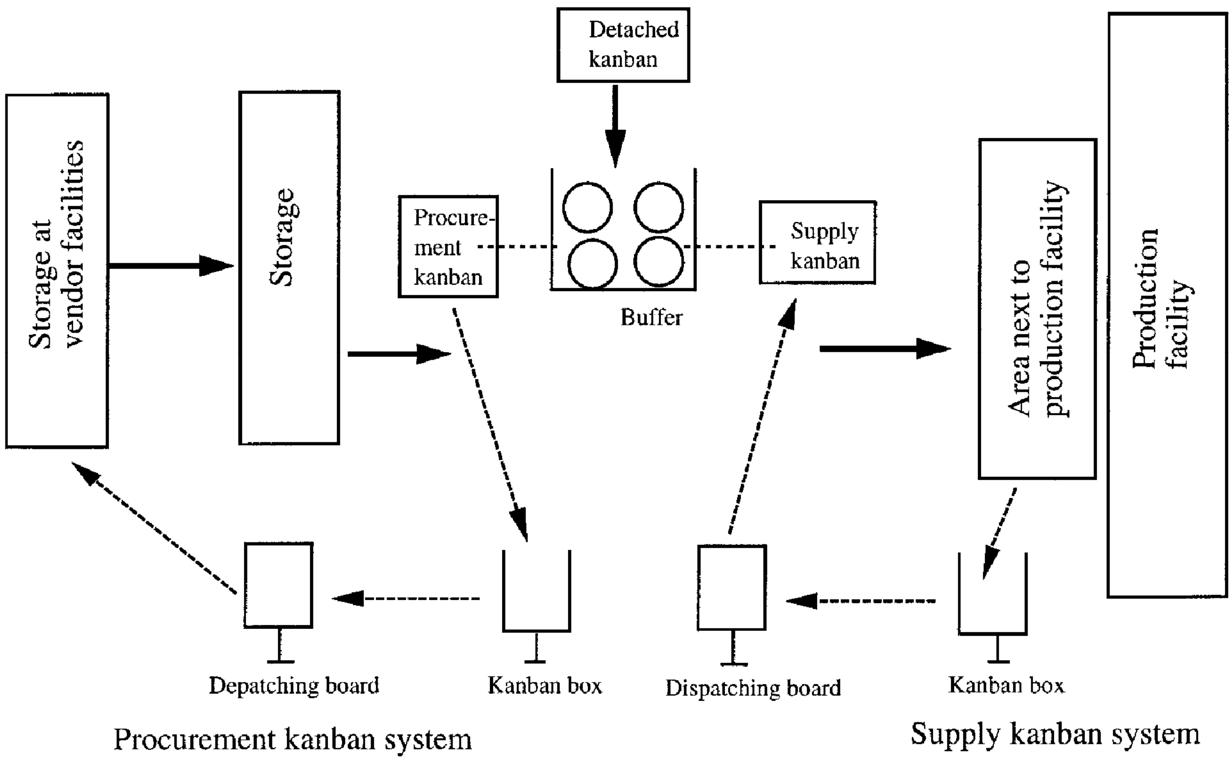


Figure 10. The Kanban system receiving parts from external vendors.

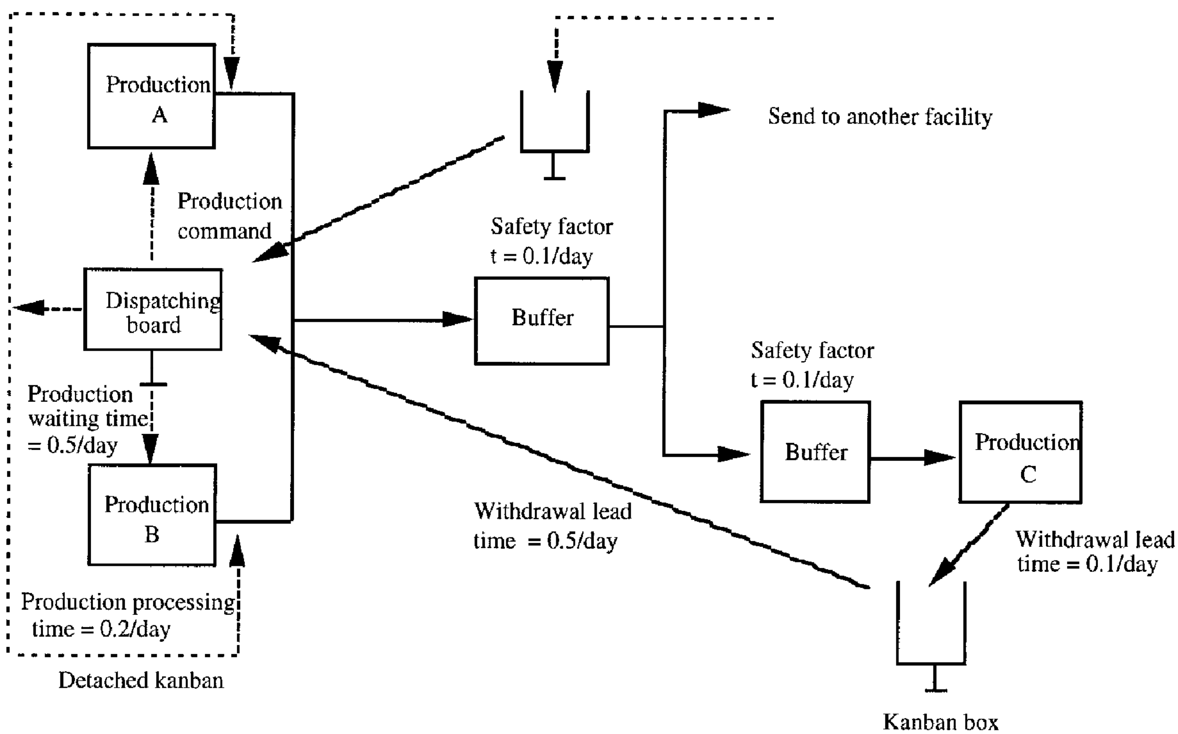


Figure 11. The cycle time of Kanbans.

1.6.4. *Adjustment of the Kanban system*

(1) *Insertion maintenance action*

Insertion maintenance takes place when the number of Kanbans used in a current planning period is larger than the number of Kanbans used in the previous period. Additional Kanbans are introduced to the system immediately after withdrawing the production Kanbans and placing them on the dispatching board.

(2) *Removal maintenance action*

Removal maintenance, similar to the insertion maintenance, takes place when the number of Kanbans used in the current planning period is smaller than the number of Kanbans used in the previous planning period. The additional Kanbans are always removed immediately after withdrawing the production Kanbans and removal of an equivalent number of Kanbans from the dispatching board.

## 2. Software approaches

Previous research approaches of Kanban pull systems included simulation, mathematical, and stochastic modelling (Uzsoy and Martin-Vega 1990). The research published has mainly concentrated on modelling Kanban systems in a repetitive (job shop) environment, determining the number of Kanbans in order to optimize the system performance, and comparing Kanban systems.

### 2.1. *Modelling Kanban systems*

2.1.1. *Simulation models.* The simulation studies of JIT-Kanban systems can be broadly classified as: (1) explorative analysis of pull systems (JIT with Kanban); (2) comparative analysis of push and pull systems. Reviews of simulation modelling are presented in Yavuz and Satir (1995a,b) and Chu and Shih (1992). Simulation studies were also carried out by Huang *et al.* (1983), Philipoom *et al.* (1987), Rees *et al.* (1987), Krajewski *et al.* (1987), Sarker and Harris (1988) and Sarker (1989), where the various aspects of the JIT doctrine and its implementation in pull systems were presented.

Chu and Shih (1992) studied the use of simulation in JIT production. They showed that numerous simulation-related statistical issues had been neglected in the previous studies. This may have caused some simulation results to be difficult to explain.

Huang *et al.* (1983) simulated a JIT Kanban system using a Q-GERT model. The results indicated either the infeasibility of applying the Kanban approach to US manufacturing or necessary environmental changes if considered for implementation.

Krajewski *et al.* (1987) developed a large simulation model capable of representing diverse manufacturing environments. They showed that the performance of a Kanban system is sensitive to the manufacturing environment. The benefits of implementing Kanban systems result from the environment, not the systems themselves.

Sarker (1989) developed a SLAM model of a Kanban pull system under different conditions, which included variable processing times and machine breakdowns. Under these conditions, the sample efficiency of push and pull systems was compared.

Gupta and Gupta (1989a,b) justified some of the unique characteristics of JIT-Kanban systems by applying a dynamic simulation model. Using system-dynamic concepts, the behaviour of the system under various exogenous factors was demonstrated.

Jothishankar and Wang (1993) applied a meta-modelling approach to analyse the performance of a JIT manufacturing system. They concluded that only the assembly time, Kanban capacity, and the interaction effect between demand and Kanban capacity are statistically significant among 15 variables studied.

2.1.2. *Mathematical programming models.* Deterministic mathematical programming models are used to optimize some objective functions of the Kanban system (Bitran and Chang 1987, Li and Co 1991, Bard and Golany 1991). This approach is suitable for a JIT-Kanban system since the repetitive environment is deterministic. However, it might not be appropriate in a dynamic environment.

Yavuz and Satir (1995a) studied the Kanban-based operations of a mixed manufacturing line. Features of Kanban-based simulation studies were surveyed for the single-card or two-card systems and the type of experimentation purpose (explorative or comparative). Yavuz and Satir (1995b) also reviewed selected published research on Kanban-based operational planning and control of flow lines and focused on simulation models.

Kimura and Terada (1981) provided several basic equations for the Kanban system in a multi-stage serial production environment. Bitran and Chang (1985) presented an optimization model for the Kanban system in a multi-stage assembly production setting and developed a solution procedure. Philipoom *et al.* (1987) applied a mathematical programming approach to determine the number of Kanbans for a single-Kanban (recorder point) system.

Gravel and Price (1988) pointed out that applying Kanban systems in a job-shop environment might be feasible under the assumptions that the processing time was constant and setup time was negligible. However, these are essential for the adaptability of Kanban system to the job-shop environment.

Mitwasi and Askin (1994) modelled the multi-item, single-stage Kanban system as a non-linear mathematical programming model with dynamic demand. They concluded that the inventory function in the Kanban system is to stablize demand rather than balance the setup cost. It is unlike the traditional inventory models, such as the economic lot size scheduling problem (Elmaghraby 1978, Zipkin 1991), where setup considerations lead to carefully planned cyclical production schedules, additional Kanbans may need to be added to account for the mean number of containers awaiting replenishment.

2.1.3. *Stochastic models.* In the stochastic approach, the pull demand and the processing time are modelled as random variables. Markov chains are often used to describe the system behaviour. The Poisson process arrivals and exponential processing times are the general assumptions (Mitra and Mitrani 1990, Deleersnyder *et al.* 1989, Buzacott 1989).

Deleesynder *et al.* (1989) developed a discrete time Markov process model for an *N*-stage serial system. Under the assumptions of a finite pool of raw material at the upstream station, and a similar pool of demand for finished products following the downstream, Mitra and Mitrani (1990) constructed a stochastic model of a cellular manufacturing facility.

Berkley (1987) showed that a base stock system with a single inventory buffer between each pair of stations is equivalent to a tandem queue. Other papers that studied base stock Kanban systems by the tandem queue theory were by Davis and Stubitz (1987), Deleersnyder *et al.* (1989), Ebrahimpour and Fathi (1985), and Sarker and Fitzsimmons (1989).

Glasserman and Yao (1994, p. 107) presented a tandem model (a, b, k) for the Kanban system, Siha (1994) developed a continuous time Markov model for pull production systems. The various allocation patterns of Kanban capacity and mean production time over the system stations were studied. It was found in some cases that a certain 'funnel' pattern can improve the system performance. Since this finding contradicts the concepts presented in papers that favoured a 'bowl' pattern, some possible interpretations were presented by Siha (1994). Overall, the results produced design guidelines that should be useful in industrial applications.

### 2.2. *Design methodologies*

Different methodologies for the design of Kanban systems have been studied in the literature, for example:

- Design with the server network generator (SNG) (Bouchentouf-Idriss and Zeidner 1991).
- Design with Petri nets (Di Mascolo *et al.* 1991).

### 2.3. *Optimizing the number of Kanbans*

Most studies have concentrated on operational control problems and performance analysis of JIT manufacturing systems, emphasizing the determination of the number of Kanbans (Deleersnyder *et al.* 1989, Berkley 1987, Bitran and Chang 1987, Huang *et al.* 1983, Jordan 1988, Kim 1985, Rees *et al.* 1987, Sarker and Harris 1988, Sarker and Fitzsimmons 1989, Villeda *et al.* 1988, So and Pinault 1988, Kimura and Terada 1981, Krajewski *et al.* 1987, Price *et al.* 1995).

Philipoom *et al.* (1987) performed a simulation study of a Kanban system and reported that factors, e.g. feed rate, machining utilization, coefficient of variation of processing times, and auto-correlation between processing times, affect the number of Kanbans.

Monden (1983a,b) indicated that certain rules must be followed in order to achieve JIT. One of them is that the number of Kanbans between two adjacent stations represents the maximum inventory level and, therefore, should be kept at minimum. The relationship and the trade-off between inventory and the number of Kanbans has been shown elsewhere, e.g. Monden (1983a,b), Japanese management Association (1986), and Shingo (1987, 1988). Specifically, it has been pointed out that the fewer the Kanbans, the better the systems. With fewer Kanbans, sensitivity of systems is greater (Japanese Management Association 1986).

Davis and Stubitz (1987) determined the number of Kanbans at each station for optimal performance using simulation and response surface methodology. Philipoom *et al.* (1987) investigated the factors that influence the number of Kanbans required for a single workcentre by examining the formula for the number of Kanbans used at Toyota (Monden 1983a, pp. 167–179). This methodology was further extended in Rees *et al.* (1987) to dynamically adjust the number of Kanbans by using a forecasted demand and estimated lead time.

Wang and Wang (1990) discussed the role of Kanbans in a JIT production system in the context of maintaining a minimum level of WIP inventory. A model for determining the optimal number of Kanbans for three production settings (one station to one station, OSTOS; multiple stations to one station, MSTOS; multiple stations to multiple stations, MSTMS) was presented. OSTOS is applicable to JIT machining shops. MSTOS and MSTMS are suitable to JIT assembly shops.

Ohno *et al.* (1995) devised an algorithm of determining optimal values of the safety stocks included in the popular formulas for computing the number of Kanbans.

Jothishankar and Wang (1992) applied stochastic Petri nets to optimize the number of Kanbans.

### 2.4. *Control approaches*

Most studies focused on the shop control methodology, allocation of a fixed number of Kanbans and buffers, and batch size control.

Chaudhury and Whinston (1990) presented an efficient, decentralized and adaptive control methodology for flow shops. The methodology is based on stochastic automata methods for modelling learning behaviour. It was suggested that such a methodology can be used with a Kanban-type control technique to make flow shop systems more flexible and adaptive. The relationship between the control model and computational models such as neural computing was discussed.

Cheng (1993) proved that with a general arrival process and exponential service times, the job completion, job departure, and Kanban generation processes are increasing concave functions of the initial inventory and Kanban counts.

Karmarkar and Kekre (1989) studied the effect of batch size policy on a production lead time, and hence on the inventory level and cell performance. Both single- and dual-card Kanban cells and two-stage Kanban systems were modelled as Markovian processes, and the effect of batch sizes on the expected inventory and back order costs were studied. It was further shown that batching policy has a significant impact on the cost. The effect of varying the card count in the cell was also examined.

Albino *et al.* (1992) modelled a single-product and multi-stage manufacturing line with reduced resource failures and controlled by a two-card Kanban system using discrete-event simulation. Several performance measures were evaluated to determine optimal operation policies given resource failures. In addition, different maintenance policies were implemented in order to better understand their impact on the overall system performance.

Yanagawa *et al.* (1994a,b) dealt with optimal operation planning of the constant-number-of-withdrawal-Kanban system with variable lead-times and different consumption rates of parts for each production unit. The behaviour of the optimal operation planning which minimizes the average total operation cost was shown by means of simulation analysis of various values of parameters: the order cost, the range of consumption rates of parts, and the range of lead times for delivery.

Mitra and Mitrani (1990) described and analysed a scheme for coordination of cells in large-scale manufacturing facility. Many cells in a tandem configuration and a fixed number of cards in each cell were considered. Some rules specified the lead time for each manufacturing cell. The cards circulated within a cell and their presence at a certain position of the cell conveys to the neighbouring cells the status of the cell inventory. The results were presented in three parts:

(1) Their scheme was shown to dominate the classical scheme in terms of the throughput rate.
(2) A scheme for approximate analysis of the performance of the Kanban system by examining first a signal cell in isolation and then combining the isolated cells through fixed-point equations was presented.
(3) The throughput-rate–inventory relationship of the Kanban scheme was observed to be superior to that of the classical scheme.

Mitra and Mitrani (1991) developed another model for a stochastic demand.

Pervozvanskiy and Sheynis (1994) constructed a model of the system for random manufacturing and demand processes, which allows determination of optimum values of system parameters. A through Kanban manufacturing control system was proposed that is more effective (according to the results of simulation) than the commonly used Kanban system.

Tayur (1993) studied the structural properties and a heuristic for Kanban-controlled serial lines, and determined:

(1) The optimal solutions in the allocation and partitioning problems given a total fixed number of Kanbans.
(2) The reduced computational effort usually required to study these systems.
(3) The development of a combinatorial measure as a surrogate for the mean throughput based on structural results; e.g., in a five-cell line to be allocated (1, $C_1$, $C_2$, $C_3$, 1) is better than other allocations.
(4) The demonstration of which structure with optimal allocations is insensitive to the variability in a system with balanced lines.

### 2.5. *Scheduling approaches*

Most studies have been concerned with levelling the schedules for a mixed model (Miltenburg 1989, Miltenburg and Sinnamon 1989, Kubiak and Sethi 1989). Garey *et al.* (1988), and Inman and Bulfin (1991) studied the problem of minimizing the total earliness and tardiness of schedules.

Mitwasi and Askin (1994) investigated the use of Kanban control at workcentres which produce multiple items with dynamic, random demand. The dynamic aspects of demand may cause temporary capacity shortages. The Kanban control system must quickly react to the random changes of the demand. By selecting different numbers of Kanbans, the dynamic aspects can be accommodated. A mathematical model was developed and shown to reduce the original problem to a simpler one.

Berkley (1993) compared the performance of the first come-first serve (FCFS) and shortest-processing-time (SPT) sequencing rules for a Kanban system with a varying buffer capacity. It was known that the optimal job sequencing varied with the buffer capacity (Park 1987). FCFS and SPT rules were tested to justify the use of the FCFS rule in Kanban systems in industry while the SPT rule is usually shown to maximize production and minimize inventory and lead time based objectives of just-in-time manufacturing. A second objective was to introduce the concept of blocking by part type found in Kanban systems processing several different parts types. As Uzsoy and Martin-Vega (1990) observed, the application of Kanban systems to a complex manufacturing environment has created a need to learn how these systems operate when there are several part types processed on the same line.

2.5.1. *Comparative studies* (Berkley 1993)

(1) The relative performance of FCFS and SPT* rules changes with the processing-time variability and input buffer capacity. SPT* is the shortest processing time rule when material-handling blocking is by part type.
(2) For both instant and periodic material handling, increasing the input buffer capacity alone has little effect on the average SPT* production rate and inventory. This is because the benefits of a larger total buffer space are completely offset by a greater frequency of material-handling blocking by part type. On the other hand, increasing the output buffer capacity alone increases the average SPT* production rate and the amount of inventory.
(3) Use of the SPT* sequencing rule can cause job-passing and material-handling operations to be blocked before input buffers are entirely full.
(4) Exponential processing times and a small input buffer capacity reduce the frequency of material-handing blocking by part type and the SPT* rule increases the average production rate and decreases the average level of inventory.
(5) For normal processing times and a large input buffer capacity, the FCFS rule increases the average production rate and inventory volume more than the SPT* rule.
(6) The use of the FCFS rule is recommended when the processing times of a batch of Kanbans are relatively constant. However, if the processing times of a batch of Kanbans are highly variable, perhaps because different part types require different processing times at each station, one should consider the use of SPT* for a system with small input buffer capacity.
(7) As the input buffer capacity is reduced in response to improved production processes, SPT* performance is likely to improve relative to FCFS.

2.6. *Comparing Kanban systems with other systems*

Numerous studies have compared Kanban systems with the MRP system (Petroff 1993 pp. 5–13, Hernandez 1989 pp. 14–20, Dürmusoglu 1991, Rees *et al.* 1989, Schonberger 1982a pp. 130–143 and 1982b pp. 1–14, and 1983, Grüwald *et al.* 1987, Sarker and Fitzsimmons 1989). The stock (Q , r) policy and the tandem queuing model in the generalized semi-Markov processes were also compared with Kanban systems (Axsäter and Rosling 1993, Berkley 1987, Glasserman and Yao 1994 pp. 107–108).

Axsäter and Rosling (1993) identified a Kanban-policy as a restricted type of installation stock $(Q_n, r_n^i)$-policy where:

(1) The reorder point $r_n^i$ of item $n$ is an integer multiple of its lot size $Q_n$.
(2) Backlogs are not subtracted in the definition of the installation inventory position.

Glasserman and Yao (1994 pp. 107–108) concluded that a generalized Kanban approach can be viewed as the approach of the general tandem (a, b, k) model implemented through cards. At each stage $i$, in addition to the $k_i$ Kanbans, there are two other types of cards: $a_i$ conveyance cards and $b_i$ production cards. The conveyance cards and the production cards are attached to raw jobs and finished jobs, respectively. The conveyance cards authorize admission to a stage; for a job to enter stage $i$, there must be one conveyance card, in addition to one Kanban available at that stage. The production cards, on the other hand, authorize service; for service $i$ to begin processing a job, the job must first be issued a free production card. When the raw job completes service, the production card is attached to it and conveyance card is detached and made available to admit another job. When a job leaves a stage, both its Kanban and production card are detached. Through this implementation, at each stage $i$ the total number of raw jobs is limited to $a_i$, the total number of finished jobs is limited to $b_i$, and their sum is limited to $k_j$.

Rees *et al.* (1989) compared an MRP lot-for-lot system and a Kanban system in an ill-structured production environment. It was determined that the MRP lot-for-lot system is more cost-effective than the Kanban system as the MRP system carries less inventory and requires fewer setups. Krajewski *et al.* (1987) concluded that working with factors, e.g. lot sizes, setup times, yield losses, workforce flexibility, degree of product customization, and product structure, to *shape* a manufacturing environment with more uniform workflows and flexibility is the key to improving performance. The Kanban system, by itself, is not crucial to improving performance, which is unlike the views of others on Kanban systems (Hall 1981, Monden 1981a,b, Schonberger 1982a, pp. 130–143 and b, pp. 1–14, and 1983, Sugimori *et al.*, 1977).

Shipper and Shapira (1989) developed a decision rule to enable *a priori* selection of a production system that should utilize a JIT or WIP type inventory control policy.

Sarker and Fitzsimmons' (1989) comparative analysis of an MRP lot-for-lot system and a Kanban system for a multistage production operation concluded that:

(1) MRP product quality would improve as lot sizes were decreased.
(2) MRP appears to handle lumpy demand better than a Kanban system, even though stochastic processing times may cause difficulties.

Gupta *et al.* (1991) provided insights into the characteristics of companies that had implemented JIT production as compared to those that had not. The authors examined the changes that the management could expect to encounter as JIT was incorporated into a manufacturing firm. The response of the survey on JIT implementation from 175 manufacturing organizations indicated that:

(1) companies that have implemented JIT had fewer costumers who purchase in higher volumes (over a period of time) than non-JIT companies;
(2) the service in response to customer requirements in JIT companies has improved faster than in non-JIT companies;
(3) product and process engineering skills are higher, and financial liquidity is better in JIT organizations.

Several differences that were expected to exist between the two types of companies were not supported by the data. It was believed that JIT companies should have significantly fewer suppliers than non-JIT companies as JIT requires manufacturers to develop ways of establishing long-term strategic partnerships with suppliers. The data, however, did not support this relationship. Also, contrary to expectations, JIT companies did not exhibit less vertical integration and did not emphasize effective coordination among functions to a greater extent than non-JIT companies. Finally, the results showed that JIT companies did not have the ability to change products in response to the changes in demand faster than non-JIT companies. JIT companies did not have more flexibility in rerouteing jobs in case of machine breakdowns.

### 2.7. *Case study*

A number of authors have examined the advantages of Kanban systems, e.g. Kimura and Terada (1981), Monden (1981a), Schonberger (1983), and Gupta and Gupta (1989a). The following case studies justify some advantages.

(1) Singh *et al.* (1990) developed a Kanban system and simulated it with GPSS.
(2) Ichihashi (1990) modelled a CIM-Kanban system to handle production control, quality control, manufacturing line control, and office and technical systems based on a number of manufacturing modules (cells) in Nippondenso Kota plant.
(3) Sohal and Naylor (1992) described the Kanban system used in a number of different areas, for example a small manufacturing firm. Even in a short period of time and with limited resources, the company achieved striking results.
(4) Sohal *et al.* (1993) presented a system integrating CNC technology and the JIT Kanban system. The results showed that the changeover and setup times reduced from 5–6 hours to about 90 seconds; stockouts or shortages of components were totally eliminated; the total stock was reduced by over 50%; and the quality of finished products improved significantly with the new production system.
(5) Several other studies were concerned with Kanban systems applied to different environ-

Table 2. Summary of previous studies of Kanban systems.

| Classification | Feature of most focused studies | References |
|---|---|---|
| Models | | |
| Simulation models | (1) Explorative analysis of JIT with Kanbans<br>(2) Comparative analysis of pull and push systems | Chu and Shih (1992), Huang *et al.* (1983), Philipoom *et al.* (1987), Rees *et al.* (1987), Krajewski *et al.* (1987), Sarker and Harris (1988), Sarker (1989), Gupta and Gupta (1989a,b), Jothishankar and Wang (1993), Yavuz and Satir (1995a,b) |
| Mathematical programming models | Optimizing some objective functions of Kanban systems, e.g., throughput WIP, and number of Kanbans, assuming deterministic environment | Bitran and Chang (1987), Li and Co (1991), Bard and Golany (1991), Kimura and Terada (1981), Philipoom *et al.* (1987), Gravel and Price (1988), Mitwasi and Askin (1994), Yavuz and Satir (1995a,b) |
| Stochastic models | Optimizing some objective functions of a Kanban system assuming that demand and process time are random variables, Markov chains and tandem queues are often used to describe the system behaviour. | Mitra and Mitrani (1990), Deleersnyder *et al.* (1990), Berkley (1987), Buzacott (1989), Davis and Stubitz (1987), Ebrahimpour and Fathi (1985), Sarker and Fitzsimmons (1989), Glasserman and Yao (1994), Siha (1994) |
| Design methodologies | Design with the network generator, e.g. SNG or Petri nets | Bouchentouf-Idriss and Zeidner (1991), Di Mascolo *et al.* (1991) |
| Optimizing the number of Kanbans | Analysing the relationship between the number of Kanbas and system behaviour, and determining the number of Kanbas so that system behaviour is optimized | Deleersnyder *et al.* (1989), Berkley (1987), Bitran and Chang (1987), Huang *et al.* (1983), Jordan (1988), Kim (1985), Rees *et al.* (1987), Sarker and Harris (1988), Sarker and Fitzsimmons (1989), Villeda *et al.* (1988), So and Pinault (1988), Kimura and Terada (1981), Krajewski *et al.* (1987), Monden (1983a,b), Japanese Management Association (1986), Shingo (1987, 1988), Davis and Stubitz (1987), Wang and Wang (1990), Jothishankar and Wang (1992) |
| Control approaches | Optimizing system behaviour by the studies of shop control methodology, e.g. decentralized and adaptive control methdology, lot size policy, and the allocation of a fixed number of Kanbans | Chaudhury and Whinston (1990), Cheng (1993), Karmarkar and Kekre (1989), Albino *et al.* (1992), Yanagawa *et al.* (1994a,b), Mitra and Mitrani (1990, 1991), Pervozvansky and Sheynis (1994), Tayur (1993) |
| Scheduling approaches | Levelling schedules of a mixed model | Miltenburg (1989), Miltenburg and Sinnamon (1989), Kubiak and Sethi (1991), Garey *et al.* (1988), Inman and Bulfin (1991), Mitwasi and Askin (1994), Berkley (1993), Uzsoy and Martin-Vega (1990), Price *et al.* (1995), Ohno *et al.* (1995) |
| Comparative studies | The comparison of Kanban systems with MRP, stock policy and tandem queuing network | Petroff (1993, pp. 5–13); Hernandex (1989, pp. 14–20); Dürmusoglu (1991); Rees *et al.* (1989); Schonberger (1982a, pp. 130–143 and b, pp. 1–14, and 1983), Grüwald (1987), Axsäter and Rosling (1993), Berkley (1987); Glasserman and Yao (1994, pp. 107–108); Shipper and Shapira (1989), Sarker and Fitzsimmons (1989), Gupta *et al.* (1991) |
| Case studies | Industrial applications | Singh *et al.* (1990), Ichihashi (1990), Sohal and Naylor (1992), Sohal *et al.* (1993), Sohal and Naylor (1992), Olhager and Östlund (1990), Harvey and Jones (1989) |

ments, e.g. in a small manufacturing firm (Sohal and Naylor 1992), in a semi-repetitive make-to-order environment (Olhager and Östlund 1990), and in an aerospace environment (Harvey and Jones 1989).

### 2.8. *Summary of previous studies*

The recently developed methodologies for Kanban systems are summarized in Table 2.

## 3. Modified models of Kanban systems

The Kanban system approach is difficult to use in certain situations, namely (see Monden 1983a, p. 64):

- job orders with short production runs;
- significant setups;
- presence of scrap;
- large, unpredictable fluctuations in demand;
- the need for complex information and hierarchical control system in the shop.

Several modified models were developed to overcome these shortcomings of Kanban systems.

### 3.1. *The constant WIP (CONWIP) model*

*Reason*

Kanban is intrinsically a system for repetitive manufacturing (Hall 1981) and it is not appropriate for a shop controlled by job orders.

*Model*

Spearman *et al.* (1989) presented a new pull system called CONWIP (CONstant Work In Process). The WIP was kept constant by fixing the total number of Kanbans in the system. The purpose of the model was to present a system that possesses the benefits of a pull system and could be used in different production environments.

*Model description*

CONWIP is a generalized Kanban system. Also, it is an integrated system that offers the benefits of JIT systems and is applicable to a broader range of production environments than the traditional JIT approach. CONWIP is focused on the interactions between the planning modules at the different levels in the hierarchy and on the architecture linking them. Like a Kanban system, it relies on signals. A card is attached to a standard container of parts at the beginning of the process. When the container approaches the end of the process, the card is removed and sent back to the beginning where it waits in a card queue to eventually be attached to another container of parts. CONWIP production cards are assigned to the production line. Part numbers are assigned to the cards at the beginning of the production line. Figure 12 illustrates the operation of the CONWIP system.

*Main difference from the Kanban system*

(1) Uses backlog information to dictate the part number sequence.
(2) Cards are associated with all parts produced on a line rather than individual part numbers.
(3) Jobs are pushed between workstations in series once they have been authorized by a card to enter the line.

*Results*

Many of the benefits of CONWIP can be attributed to the fact that it is a pull-based production system (e.g. shorter flow times and reduced inventory levels). However, the system does offer some distinct advantages over the Kanban system. One of them is that it can be used in some production environments where Kanban

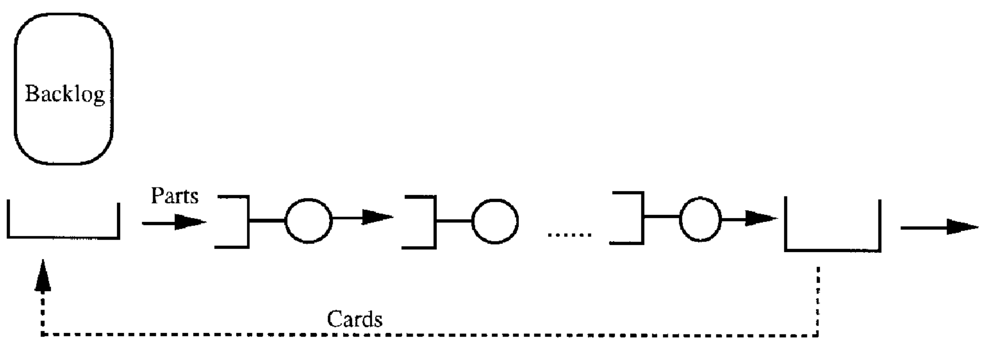


Figure 12. The CONWIP system.

is not practical due to too many card numbers or because of high setups. By allowing WIP to be collected in front of the bottleneck, CONWIP can function with lower WIP and less production control personnel than in the Kanban system. Spearman *et al.* (1990, 1992) concluded that:

(1) CONWIP is more general than a Kanban system.
(2) CONWIP is more effective than a Kanban system.
(3) CONWIP not only has better customer service, e.g. less tardy jobs than a pure Kanban system, but also solves certain implementation problems, e.g. difficult to reduce setups or to optimize synchronization of parts production.

### 3.2. *The generic Kanban system*

*Reason*

With variable demand and processing times, it is difficult to set the master schedule. Also, line balancing and synchronization in the receptive system are impossible to attain. A Kanban operation is generally not applicable to a dynamic environment with variable demands and variable processing times (Hall 1981, Huang *et al.* 1983, Finch and Cox 1986, and Krajewski *et al.* 1987).

*Models*

(1) A dynamic environment may be changed (or simplified) toward the repetitive system and adopt the Kanban control discipline. However, this requires significant changes in the system (Huang *et al.* 1983, Finch and Cox 1986), which is not practical in many cases because many companies cannot afford to do so.

(2) Chang and Yih (1994a) proposed a generic Kanban system—a modified Kanban discipline—for dynamic environments. The generic Kanban system does not have all the benefits of JIT Kanban system. However, it is adaptable because it has advantages over other production systems under the same dynamic conditions.

*The model description*

To operate a generic Kanban system, determining the number of Kanbans and lot sizes used in the system is needed. The number of Kanbans and job lot size directly affect system performance. One of the approaches to determine the number of Kanbans at each station and lot sizes of job types to optimize the generic Kanban system performance, was proposed (Chang and Yih 1994b). This approach included formulating the multi-objective optimization problem with a utility function and searching the maximum utility value with a modified simulated annealing (SA) algorithm.

A generic Kanban system includes two phases: acquisition phase and actual production phase.

*The Kanban acquisition phase*: in the generic Kanban system, the demand is unknown due to the dynamic environment. When a demand arrives in the system, Kanbans have to be issued for all stages because no parts at any stage are made beforehand. Only when the raw material arrives at the initial station can the actual production of the system begin. Moreover, not every Kanban at any stage can be issued immediately since the number of Kanbans at each stage is limited. A request may be deferred if at a particular stage Kanbans are not available.

*The actual production phase*: when a job finishes processing at one stage, it is moved to the next downstream stage and the attached Kanban at this stage is dropped. This Kanban is acquired by the next request.

*Main difference from the Kanban system*

The situation in the actual production phase is different from a JIT Kanban system where the free Kanban triggers a new production immediately because products are made repetitively in this environment.

*Results*

To show the adaptability and superiority of such a system, other control methodologies such as push systems, dedicated Kanban systems, and CONWIP systems were studied and compared. The simulation results are listed below (Chang and Yih 1994b).

(1) Trade-offs exist between cycle time and WIP level in generic Kanban systems. The lot size has an impact on the system performance.
(2) The generic Kanban system behaves similarly to a push system except that a decision-maker has more flexibility in relocating resources.
(3) The performance of the generic Kanban system is preferred to the dedicated Kanban system because it provides simpler production control and dominates the performance, e.g. less WIP. It is also preferable to CONWIP because of higher flexibility, e.g. more jobs are allowed to enter the system. The SA algorithm is shown to provide similar solutions in shorter time in the generic Kanban system than in the traditional one.

### 3.3. *Modified Kanban system in a semiconductor manufacturing environment*

*Reasons*

A conceptually pure Kanban system is not suitable for semiconductor fabrication due to the nature of the manufacturing process. The current systems are designed to prevent uneven line loading resulting from various operational problems. Even after the fundamental problem has been solved, the residual impact on production due to disrupted WIP flow could last for weeks. Thus, poor line loading leads directly to increased cycle times, poor predictability, and more defective products

*Models*

Otenti (1991) described a modified Kanban WIP control system successfully implemented in a semiconductor (CMOS) fabrication facility. The approach was to set up a series of Kanbans with caps on lots allowed to enter the system. No additional lots would be allowed to move into a Kanban system if the WIP level in the system had reached the maximum allowable limit.

*Results*

Cycle time dropped from 44 days to 30 days, a 32% improvement.

Kraft (1992) described a tool which is being currently used at Texas Instruments with modified Kanban JIT scheduling incorporated to improve the line balancing and WIP flow.

*Results*

Cycle time reduced by more than 36%.

### 3.4. *The integrated push-pull manufacturing strategy*

*Reasons*

(1) A pull strategy is not necessarily applicable to all manufacturing environments.
(2) Many manufacturing firms using pull systems are interested in attaining the simplicity of push systems.

*Model*

Olhager and Östlund (1990) combined a push and pull system into a system through three points, the customer order point (i.e. the point where a production is assigned to a specific customer), the bottleneck resources, and the product structure.

*Results*

In the integrated push-pull system, the major issue is the linkage of the manufacturing strategy with the business strategy. The issue can be solved by changing the manufacturing planning and control focus. In the new system, a push principle is applied to the focused machines (bottleneck machines) and succeeding production stages, and incoming parts are pulled. This has resulted in improved dependability of delivery and production flexibility. A case study in a semirepetitive, make-to-order environment illustrated some potential benefits from such an integrated approach.

### 3.5. *The periodic pull system*

Using the Kanban system, manufacturing factories at Toyota no longer rely on a computer. The reasons for having employed the Kanban system instead of a computerized system were as follows:

- Reduction of the cost of processing information.
- Rapid and precise acquisition of facts.
- Limiting surplus capacity at feeding facilities.

*Reasons*

(1) In present management systems, the volume and complexity of information has increased.
(2) For some manufacturing environments, computerization is necessary.

*Model*

Kim (1985) developed an alternative to the Kanban system, a period pull system (PPS), as an operation policy of practising a pull system. In the PPS, the manual information processing time of a Kanban system is replaced with instant on-line computerized processing.

*Model description*

In a computerized material management system, the status of material flow at all stages is reviewed at regular intervals. As the result of the review, only the exact amount of material that has been consumed at a succeeding stage (since the last review time) is allowed to be withdrawn from or produced at a preceding stage. A review interval is called a period. The time for a review is assumed to be non-negative, i.e. computer processing time. The withdrawal and production starts immediately after the review, that is, at the beginning of the period. A PPS is formulated mathematically and a solution approach is provided for target stock levels, as well as the analysis of the fluctuations of in-process material flow, on-hand stock levels, target availability, etc.

*Analogy*

One may visualize that a review time is equivalent to a Kanban pick-up time and thus, in a PPS, the imaginary Kanbans picked at a review time are delivered to a preceding stage at the same review time, i.e. instantly.

*Results*

The material lead time is much shorter than that of a

Kanban system, and the system performance improves in terms of less inventory and faster system response.

### 3.6. *Case study*

Graham (1992) described work carried out in association with Jaguar Cars to develop a steady-state Markovian model for calculating the number of Kanbans required to control single-stage processes feeding assembly lines. A Markovian model of an alternative JIT system, in which the off-line process is triggered by the passage of vehicle bodies past a point prior to the assembly area, is also described.

*Results*

(1) These models have shown that the use of a trigger system leads to lower inventory levels and a greater pressure for improvement than in the Kanban system itself.
(2) In a Kanban system the level of subassembly inventory required is insensitive to changes in the rate and average duration of body rework, whereas with the triggered system the average level of subassembly inventory is sensitive to both the rate of body rework and the duration of subassembly rework.
(3) The only incentive of a Kanban system is to reduce the rate and duration of body rework positively correlated with the value of inventory. However, in the triggered system a reduction in the expected level of body rework inventory may reduce the inventory level of all triggered subassemblies.
(4) For example, a 50% reduction in the rate of body reworking or a 50% reduction in rework time both lead to a reduction from 69 to 67 in the expected average number of engines of this type in inventory if triggering is being used, whereas with the Kanban system, 80 engines would be needed.

## 4. Conclusion and further research directions

Based on the literature reviewed in this paper, the conclusions reached are summarized as follows:

- The Kanban literature presents diverse Kanban systems.
- The concept of Kanban systems is not a panacea for all industrial problems. It is applicable to a repetitive manufacturing environment. Furthermore, the key to improving manufacturing performance is to consider such factors as lot sizes, setup times, yield losses, workforce flexibility, degree of product customization, and product structure, to shape a manufacturing environment with more uniform workflows and flexibility. The Kanban system, by itself, is not crucial for improving manufacturing performance.
- The model of Kanban operations in its simple form is a stock (Q, r)-policy or a tandem queue. However, together with autonomation (Jidoka), setup reduction, flexibility of workforce, quality control circles (QCC), the Kanban system has many advantages.
- Decreasing the lot size is an effective way to reduce the mean length and waiting time in WIP points at all Kanban levels that combine Kanbans and production stations.
- The optimal allocation structure of a fixed number of Kanbans is insensitive to the variability in the system with balanced production lines.
- The inventory function in the Kanban system is to stabilize the demand rather than balance the setup cost.
- For a Kanban system to operate effectively, it is crucial that the delivery times and quality of the upstream suppliers is reliable.
- In most practical approaches, the product/process design was not modified before implementing the JIT-Kanban system concept.

The issues that need further research are categorized as follows:

- Design of products and processes for a JIT-Kanban system.
- Development of a general model that has the advantages of Kanban systems, can be integrated with manufacturing systems of different types, and applicability of the integrated concept to a non-repetitive manufacturing environment.
- The problem of production levelling through scheduling is crucial in Kanban systems. Selecting the proper scheduling rules becomes even more important in the case of high product variety and uncertainty of processing times.
- Introduction of feeder lines into the pull system configuration adds flexibly in adjusting to the lumpy demand and the flow synchronization.
- Development of optimal bounding schemes for the sum (Minimax) objective function in the levelling schedule problem.
- The trade-off cost between more frequent material-handling and benefits of reduced WIP

when the optimal number of Kanbans is to be determined. Most previous studies only considered minimization of the throughput/WIP but ignored minimization of the total cost when the optimal number of Kanbans was determined.

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