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SYNCHRONIZED CONTROL

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Manufacturing control consists of the activities related to executing plans and comparing the actual results of these plans to the expected results. Traditional input/output control monitors differences between planned and actual inputs and outputs of a work center.

The synchronized production control approach controls the flow of materials in a production line based on actual customer demand and actual consumption of materials. Synchronized production control can be implemented in JIT or TOC environments. From the viewpoint of manufacturing types, most manufacturing companies can implement synchronized production control as long as the JIT or TOC philosophies and environments have been established. Synchronized production control approaches can be applied to continuous production, intermittent production, make-to-stock, assemble-to-order, discrete manufacturing or process manufacturing. Industries not suitable for the synchronized control approach include those that use project-based production and an engineer-to-order environment.

Traditional Production Control Approaches

- *Production Activity Control (PAC)*

  Production activity control involves the execution and control of the master production schedule and material requirement planning. PAC routes and dispatches the work to be completed through the production facilities and regulates the supply of materials. PAC must at the same time use resources efficiently while maintaining the required customer service level. MRP authorizes PAC to make detailed schedules for manufacturing, release shop orders to the shop floor, release pick orders to the material control department, control the shop orders and make sure they are completed on schedule, take care of day-to-day operations and problems, and provide the necessary support. A major technique for PAC is input/output control.

- *Input/output control*

Input/output control is a capacity control approach where planned and actual inputs and planned and actual outputs of a work center are monitored. Planned inputs and outputs of each work center are developed by capacity requirement planning and approved by manufacturing management. The control of inputs involves selecting orders of the appropriate priority and releasing them at an almost optimal rate. The control of output regulates the production rate of a work center in order to meet the production targets set in the released priority plan.

Work-in-process (WIP) inventory rises when the input rate exceeds the output rate, and decreases when the input rate is smaller than the output rate. WIP here refers to the inventory queued to be processed. In more precise terms, we call the WIP the "backlog". In a push system (see below), work centers take shop orders from management and only inputs are controlled. Therefore, when WIP inventory exists, the output rate is also the capacity of the work centers in push systems. In this case, input rates should never exceed output rates. When the backlog level becomes too high, the input rate is reduced; when it decreases, the input rate is increased. Table 1 shows a typical input/output control report of a work center. All the numbers in Table 1 are transformed into standard hours.

Table 1: Input/Output Control Report

Period			1	2	3	4	5	6
Input	Planned		95	95	98	110	100	120
	Actual		92	94	100	100	105	115
	Cumulative Variance		-3	-4	-2	-12	-7	-12
Output	Planned		100	100	100	120	120	120
	Actual		90	103	95	110	102	113
	Cumulative Variance		-10	-7	-12	-22	-40	-47
Backlog	Planned	120	115	110	108	98	78	78
	Actual	115	117	108	113	103	106	108

Just-In-Time Control

- *Push and Pull*

In a push system, production activities are performed according to schedules that are planned in advance. Shop orders are released to the shop floor where the work centers manufacture the items in the quantities and at the times indicated by the schedules. The pick orders are released to the material control department which issues materials to the shop floor, where they are used by a shop order in accordance with a given schedule. The production activities are "pushed" by the central scheduling unit. The materials are "pushed" from the preceding work center to the following work center.

In a pull system, production activities are triggered by demand originating from customers or subsequent work centers. There are no shop orders or pick orders. The work centers manufacture products in order to replace inventory depleted by consumption or to satisfy the demand from the next work center or customers. Materials are not issued until a signal comes from the next work center or customers. Therefore, the materials are "pulled" from the preceding work center to the following work center or customers.

- *Pull Signals*

Pull signals trigger the production in work centers in a production line. There is not one particular fixed format for pull signals. Many types of signals can be used. Cards or kanbans are the most frequently used pull signals. Cards are attached to containers of materials. When the materials in the containers are consumed, the cards are detached and fed back to the preceding work center to trigger the production for replenishment. Containers themselves can also be used as pull signals. When the materials are used, the empty containers flow back to the preceding work center to be refilled. Inventory within sight is also a pull signal. When a worker finds that inventory has been consumed to a certain level, he will start to replenish the materials.

- *Kanban Rules*

Kanban is a term borrowed from Chinese or Japanese. The original meaning of kanban is a board at sight. In practice, kanbans are normally cards with material information printed on them. Kanbans are used to trigger a production line or the factory. When using kanbans, the following rules must be obeyed:

1. No kanban, no production, never exceed the kanban ceiling. Kanban ceiling is the number of kanbans representing the maximal level of WIP inventory.
2. Follow FIFO in the kanban start queue. Materials must be replenished in the sequence in which they are consumed.
3. Never pass on a known defect. The following center does not take responsibility for inspecting incoming materials. A defect must not be passed on to the following work center.
4. Reduce kanbans to expose problems. As long as the system is running steadily, a small number of kanbans are removed for it does not need so many kanbans any more. WIP inventory reduces as the number of kanban decreases, and problems may occur. Kanban ceiling or WIP inventory is reduced gradually. It is a continuous improvement or a "one less at a time" practice.
5. The customer pulls material from the supplier. The following work center is a customer of the preceding work center. The preceding work center is the supplier for the following work center. Materials are moved from a supplier to a customer when the customer releases the pull signal.
6. Only active materials are allowed at the workstation. There is no inventory at any given workstation. All materials at a workstation are being processed.
7. Everything has a place and is in its place. Any material in the production line must be placed in a planned location. Nothing should appear in an unexpected place.

- *One Kanban System*

If the work centers are located near each other, WIP inventories are stocked between work centers. In this case, kanbans of one type are circulated between the storage location and the preceding work center. Figure 1 shows an example of one kanban system.

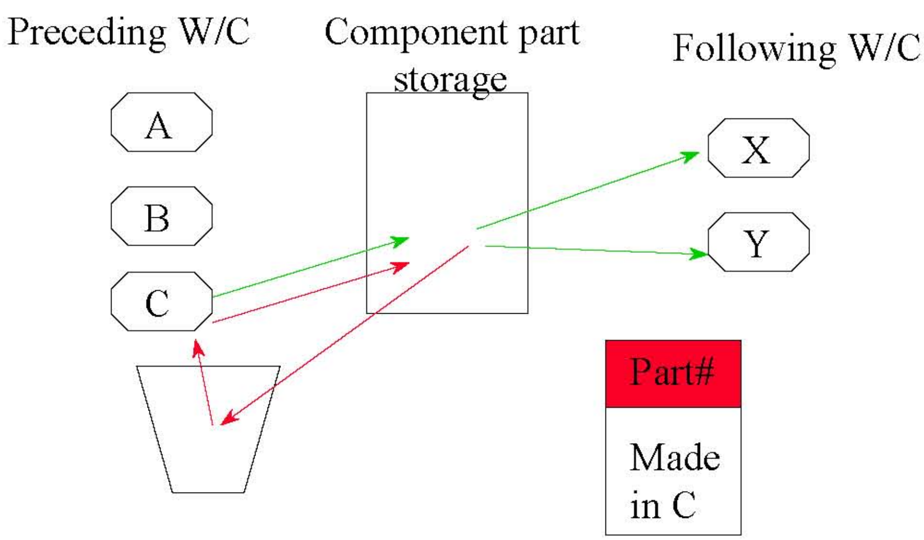

Figure 1: One Kanban System

The materials made in work center C are used in work center X and Y. A kanban is attached to each material in the storage location. When the materials are withdrawn from the storage, the kanbans are detached and are hung on the kanban box located at work center C. Work center C then produces the materials indicated by the kanbans. When C finishes its job, kanbans on the box are attached to the finished materials and are stocked in the storage. The component storage can be shared by multiple preceding and following work centers. Various materials are stored in the same area but need to be located at specific locations.

- *Two Kanban System*

If work centers are separated for a great distance, the material handling need to be performed by dedicated personnel. Since kanbans are production signals, they have to be seen by the workers at the worker centers. Other signals are needed to trigger the movement of the materials. Therefore, two types of kanbans are required. The first type is the *production kanban*. These kanbans are used to trigger the production for the work centers. The second type of kanban is the *move kanban,* which is used to trigger the movement of materials. Figure 2 and 3 show the production kanban and the move kanban, respectively.

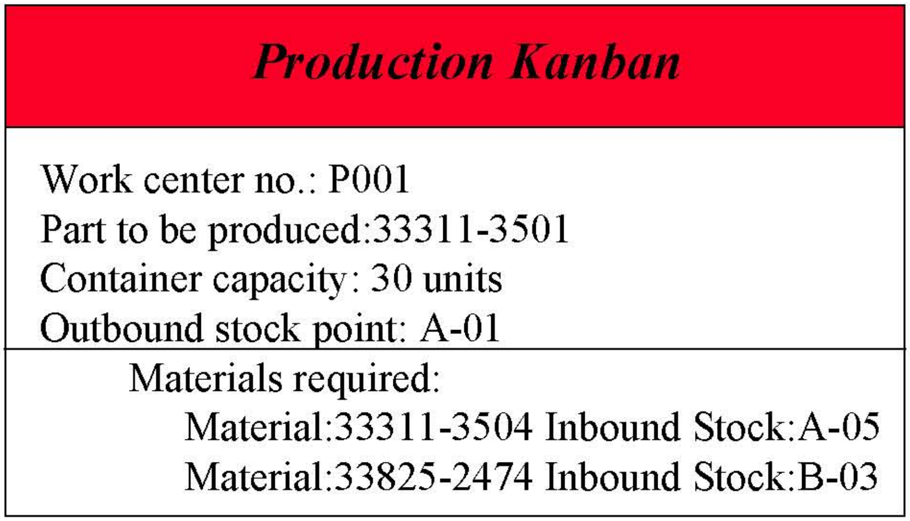

Figure 2: Production Kanban

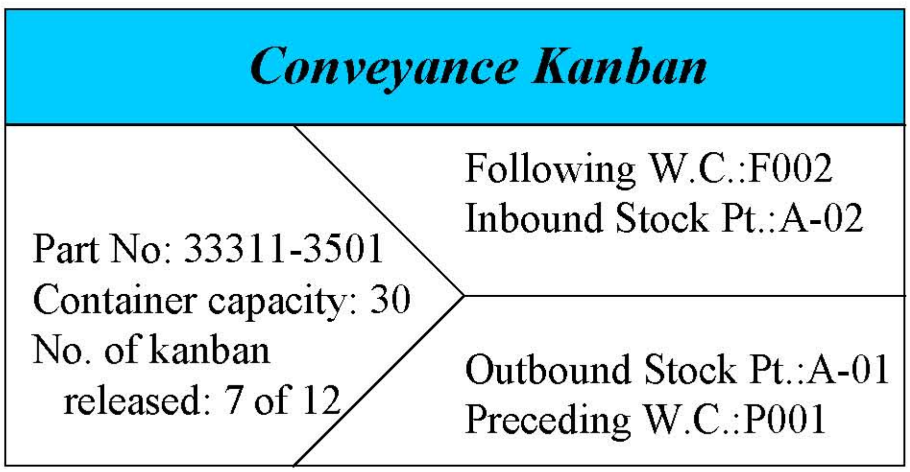

Figure 3: Move Kanban

Figure 4 shows an example of two-kanban system. P001 is the work center preceding to the following work center F002. The outbound stock point for P001 is A-01. The inbound and outbound stock point for F002 is A-02 and A-03, respectively.

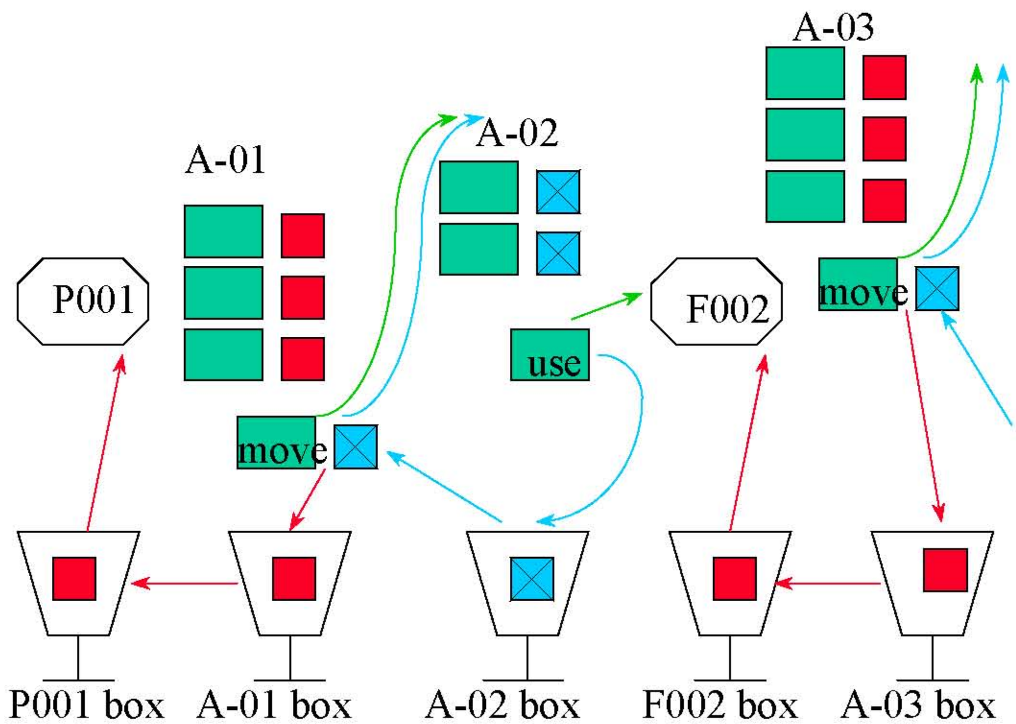

Figure 4: Two Kanban System

When the materials stored at A-02 are used by F002, the move kanbans are detached and displayed on the A-02 kanban box. The material handling people take the move kanbans to the indicated outbound stocked point of P001. At the outbound stock point of P001, materials with production kanbans are stocked in the storage location. The people in charge of material handling detach the production kanbans and display them on A-01 box, and then attach the move kanbans to the materials and move them to A-02. Production kanbans on A-01 are collected and sent to the P001 kanban box. Workers in P001 find the production kanbans and start to produce what is specified by the production kanbans. When the materials are finished by P001, production kanbans are again attached to the materials and stored at A-01.

- *Refill Kanban and Rolling Kanban*

The component storage location between work centers can store all possible materials produced by the preceding work center and is used by the following work centers, or just part of them. If all the materials produced by a preceding work center are stored, kanbans are issued for each of them, and the preceding work center continues refilling the materials as they are consumed by the following work center or customer.

We define this type of kanban as the "refill kanban". Figures 5 and 6 are examples of the lamp set discussed in Chapter Four. Both use refill kanbans. The case in Figure 5 is in a make-to-stock (MTS) environment, and all 18 possible end items are stocked in the warehouse. Customer orders are satisfied directly from the warehouse, and the last work center refills the products consumed by the customers. Figure 6 is a make-to-order (MTO) case. The last work center builds products on receiving customer orders. If the lead-time in each work center is short enough, MTO is the better choice for kanban control. A traditionally MTS product can be switched to MTO after applying JIT and kanban techniques.

If there are too many types of materials, stocking all of them in the component storage may not be economical. We define another type of kanban as the "rolling kanban" because these kanbans roll over through the production line. Rolling kanbans are not used to stock and refill all possible materials. Rolling kanbans are queued on the kanban box with limited space and are processed in a first-in-first-out (FIFO) sequence. When the kanban box of the next work center has a space, the product indicated by the first kanban queued in this work center is produced and moved to the next work center along with the kanban. In the MTS case shown in Figure 7, when a customer removes a product, the related kanbans are moved to the first work center of the production line. The first work center replenishes the material according to the incoming kanban when the next work center "pulls" it. The kanban and material are then moved to the next work center. The kanban indicates what is to be produced, and production is triggered when there is an empty kanban space in the next work center. Refill kanbans indicate what is to be produced and when. When a refill kanban shows up, production is triggered. When the first rolling kanban in the inbound queue of the following work center is removed, the first kanban in the inbound queue of the preceding work center triggers production. Figure 8 shows the rolling kanban in the MTO situation. Customer order information triggers the production in the first work center.

- *Re-work Kanban*

If the items requiring re-work are not sent out of the work center, the kanbans are retained in the work center. If a re-work item is sent out of the work center and there is no special re-work kanban, production kanbans are retained. When the re-work item returns, the production kanban is matched to it, and the process continues. If the re-work takes an extended period of time, special re-work kanbans are needed. A limited number of re-work kanbans are placed on the wall. When an item requires re-work, a re-work kanban is taken to replace the production kanban, and the production kanban is put in the position of the re-work kanban. When the item comes back, the re-work kanban and its corresponding production kanban are exchanged. The number of re-work kanbans removed from the wall indicates the level of re-work needed in a work center.

- *Emergency Kanban*

In emergency situations such as machine breakdown or material defects, the inventory might need to temporarily exceed the kanban ceiling. Emergency kanbans are issued to cope with this situation. Emergency kanbans are authorized from higher rank management, and their volume is limited. When a material with an emergency kanban is used, the emergency kanban is not re-circulated. The excess inventory is not replaced.

- *Volume of Kanban*

When materials are used by a work center, the kanbans are transferred back to their preceding work center. If the production lot size in the preceding work center equals the quantity represented by a kanban, the materials are produced and moved to refill the inbound stock of the following work center. The time required is called replenish time. The replenish time is the time from when a kanban is removed to when the material is restored. To ensure that there is enough inventory in the inbound stock of the following work center during the replenish time, the number of kanbans should be able to represent a quantity equal to at least the production rate times the replenish time. The formula is:

Number of kanbans = [(Replenish time + Allowance) * Production rate] /Container size

In the above formula, the allowance is the time by which replenish time is increased. It is meant to compensate for uncertainties. If the production lot size is larger than the quantity of materials represented by a kanban, the preceding work center does not start the production until the number of kanbans reaches the number required by the lot size. The formula is:

Number of kanban
= [(Replenish time + Allowance) * Production rate + Lot size]/Container size

For example, if the replenish time is 2 days, the allowance is 1 day, the production rate is 600, the lot size is 200, and the container size is 100, then the number of kanbans is:

Number of kanbans=[(2+1)*600+200]/100=20

The number of kanban should consider the transfer lot size. For high volume environments, a kanban is split into several transfer lots. For high mix environments, several kanbans are moved together. The number of kanbans should avoid daily or weekly multiples. The number of kanbans does not represent daily or weekly production quantity. An increase demand should be met with an increase in production rate and kanban turnover rather than an increase in the number of kanbans used.

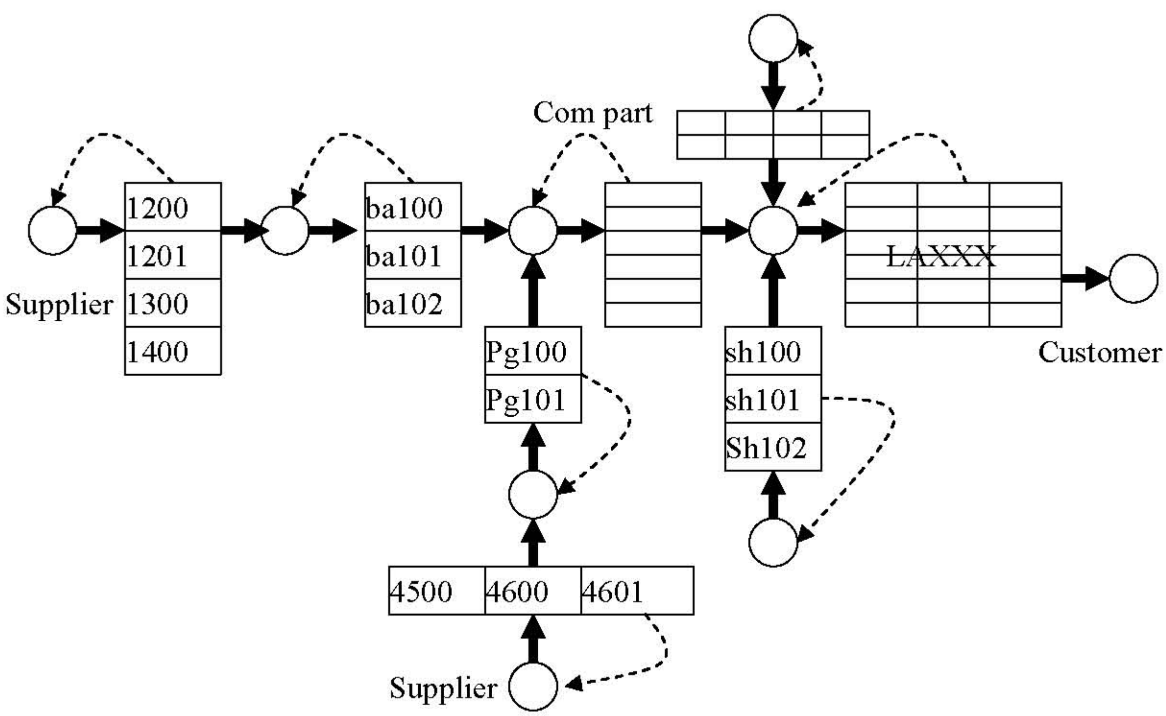

Figure 5: MTO Refill Kanban

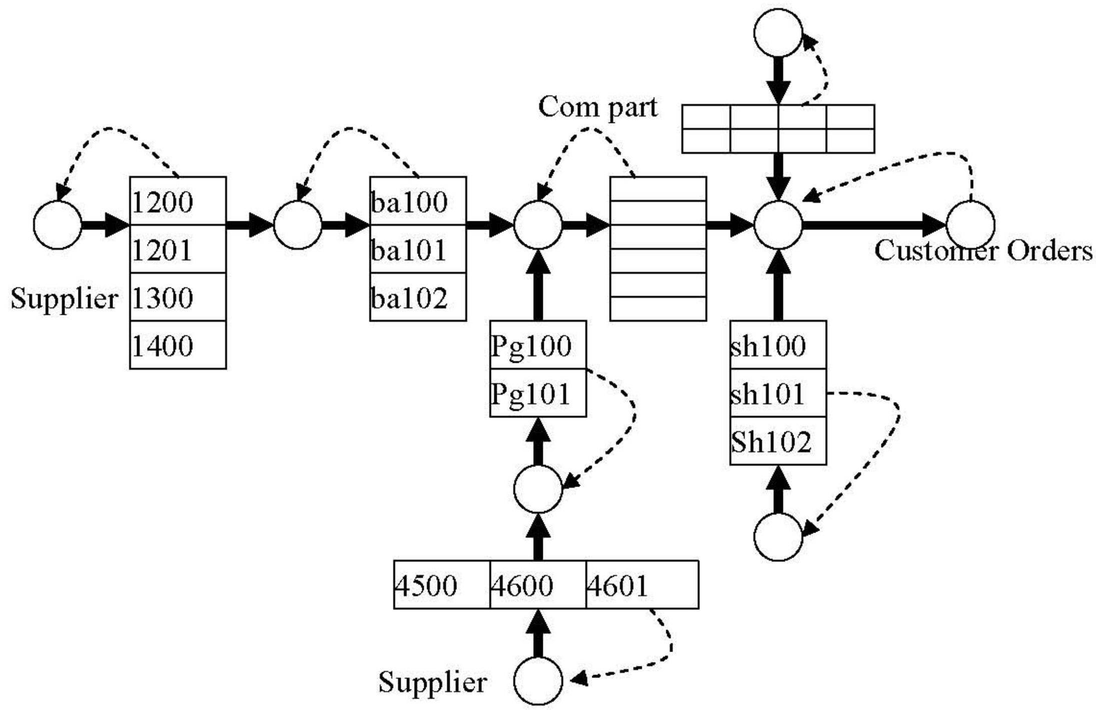

Figure 6: MTS Refill Kanban

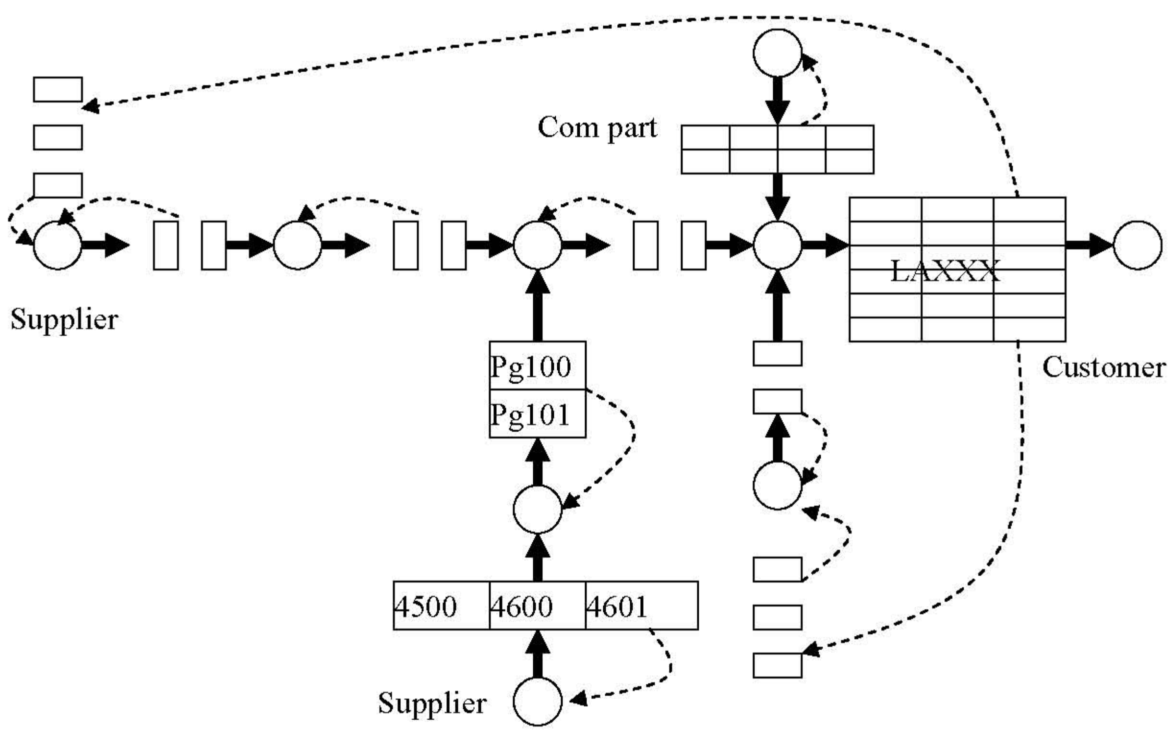

Figure 7: MTO Rolling Kanban

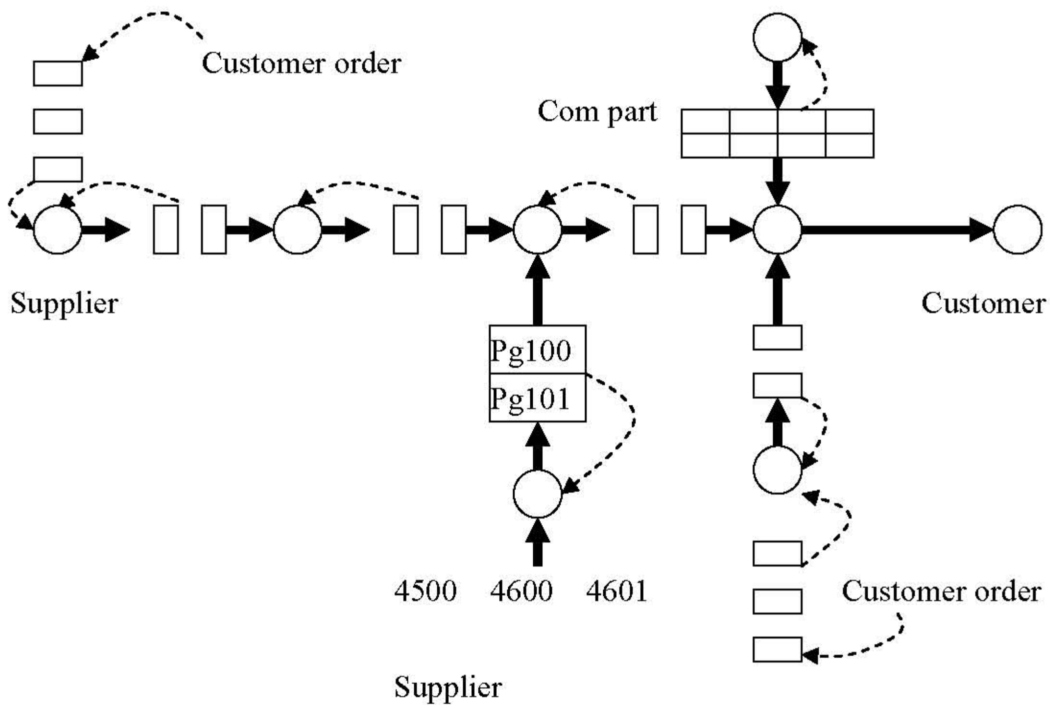

Figure 8: MTS Rolling Kanban

Theory-of-Constraints (TOC)

A constraint is any factor that prevents a system from achieving a higher level of performance. It could be physical such as a bottleneck work center, or managerial such as a policy. The theory of constraints is a management philosophy developed by Dr. Eliyahu Goldratt. If there are constraints in a system, then the system performance is limited by the constraint performance. In TOC, the control of constraints is emphasized. TOC suggests that the constraints should eventually be eliminated one by one. If there still exists constraints, TOC proposes control techniques to ensure the constraint resource is at the highest performance. Constraint management and drum-buffer-rope are important techniques in TOC.

- *Constraint management*

  Constraint management is the practice of managing resources in accordance with the theory of constraints. The steps involved in constraint management include:

  Step 1: Identify the constraints of the system.

Step 2: Exploit the constraints.
Step 3: Subordinate all non-constraints.
Step 4: Elevate the constraint.
Step 5: If the constraint is broken in step 4, go to step 1.

- *Drum-Buffer-Rope Control (DBR)*

Drum-buffer-rope is a control technique used by TOC. The purpose of DBR is to maximize the throughput of the system's constraining factor. Drum is the production rate or pace set by the system's constraint. Buffer is an inventory to protect against uncertainty and prevent the system's constraining factor from being starved. Rope is the communication process from the constraint to the first work center, or gateway operation, that controls the pace of release of materials into the system to support the constraint. Figure 9 shows an example of drum-buffer-rope control.

In Figure 9, the gateway operation is the first work center that controls the input rate of the system. When the buffer inventory drops below one third of the maximal buffer size, the "rope" instructs the gateway operation to increase the rate of material release. When the buffer rises up to two thirds of the maximal buffer size, the rope instructs the gateway to decrease the input rate. When the buffer inventory is maintained at the middle level, the input rate is kept at a moderate level.

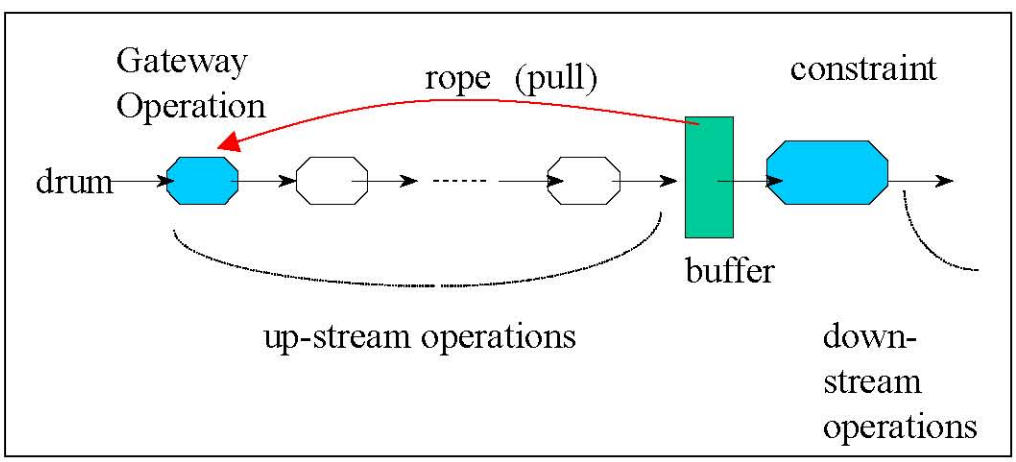

Figure 9: Drum-Buffer-Rope Control

The rope signal is a pull signal. The operations in the gateway work center are pulled from the buffer. The operations in the up-stream work centers are pushed by the gateway operation. The down-stream work centers are pushed by the constraint work center.

Drum-buffer-rope is used when the constraint or bottleneck in the production line cannot be eliminated. When the throughput of the constraint is maximized, the system performance is maximized.