UNIT 11 PROCESS INVENTORY

Objectives

After reading this unit, you would be able to:

- define what is meant by process inventory;
- discuss the type of inventories;
- identify the factors influencing the WIP inventories; and
- discuss the methods of controlling the WIP inventories.

Structure

11.1 INTRODUCTION

Purchasing and inventory control are the major areas in materials management and form the core of this subject. Inventory control gained importance in India since early seventies. This was the time when government initiated restrictions on bank credits to cover inventories on the basis of Tandon Committee Report. At that time the idea was that by holding large inventories artificial shortages of goods is effected and that results in rising of prices. However there are many more evils attached with inventories. In the previous unit you have learnt about the meaning of inventory and the systems and models prevalent to control size of inventory. In this unit, we will go further and explain three parts of inventory i.e., raw material inventory, process inventory, and finished goods inventory. Process inventory is the inventory of goods that are essential part of the production process. Many questions are raised when one talks about the control of process inventory. But the fact is that process inventories are an expensive preposition and in order to really cut the costs one has to control them. The unit thus aims at identification of factors influencing such inventories and methods to control them.

11.2 MEANING OF PROCESS INVENTORY

Process inventory is also called in-process inventory or work-in-process inventory (WIP). They are concerned with the materials or semi-finished goods on the production floor. These materials are essentially an integral part of the total production process. Each product has some stages of production attached to it and a delay in one or many stages results a delay in the time it takes for finally reaching the warehouse. These delays cause flow of other materials on hold. Maintaining a WIP is on one hand essential in ensuring that the required material is available at the time when it is required in the production process and on other hand holding a material for too long adds to your cost. There are other reasons also like lack of proper production planning; lack of coordination between purchase and production; urgency of production of another manufactured goods or an error in a machine on the production floor etc. WIPs are as expensive as the other inventories and therefore it is a must to control them. Let us first see what these inventories are? Figure 11.1 shows a generic physical flow where materials flow from suppliers/vendors to become raw material inventory. From raw materials inventory, the materials go to the production floor where different workstations at different stages transform them into finished goods. Once the finished goods are obtained, they are moved to the finished goods inventory. Various distribution centers and warehouses then comes into picture and moves the finished goods to the customers. The phase between the raw materials inventory and the finished goods inventory is performed on the production floor and involves many workstations for the conversion of the raw materials into the product and is called work-in-process. These materials that are present on the production floor are called work-in-process (WIP) or process inventory.

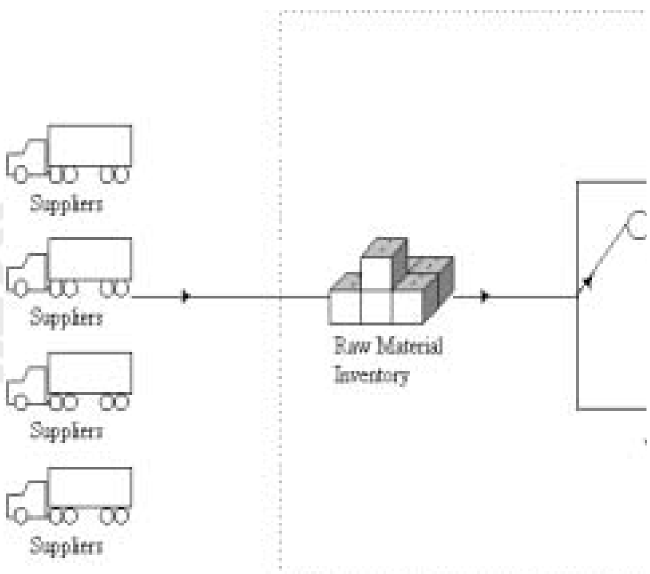

Figure 11.1: Generic Physical Flow

Source: based on Sipper et al. (1998)

As you have read in the unit 1, there is material flow as well as an information flow that manages the production system. If you divide the Figure 11.1 into three parts vertically you will see that purchasing and forecasting respectively establish interaction between external suppliers and external customers. It is inventory management that takes care of various inventories.

There are many integrated production systems designs like cellular manufacturing systems (CMS); flexible manufacturing systems (FMS) and computer integrated manufacturing (CIM) that gives high importance to reduced work in process. FMS in particular is more concerned about WIP as it mainly deals with the production floor:

11.3 INVENTORY TYPES: A REVIEW

Various inventory types are classified according to the value added while in the production process. Let us look at them once again.

Table 11.1: Types of Inventories

S.No.	Type	Definition	Description
1	Raw Materials Inventory	All items required for manufacturing and assembly process	Materials needing further processing, Ready-made Components and supplies like screws etc.
2	Work-in-process (WIP) Inventory	Materials waiting to be processed or assembled, those that are in semi-finished stage, subassemblies etc.	Materials required at different stages by different workstations, half-processed or subassemblies.
3	Finished goods Inventory	Outputs of this production process. Ready to go the customer or some other manufacturing process	Usually finished products ready to be moved to warehouses and then to the customers.

Source: based on Sipper et al. (1998)

There are many other inventories like maintenance, repairs and operating inventories (MRO), movement or transit inventories, let-size inventories, fluctuation inventories and anticipation inventories. They are classified according to the function they perform. All of them require different kind of treatment. This treatment depends on their types, need in different types of industries and cost-benefit analysis.

Inventory is a quantity of commodity that incurs cost. The costs associated with inventories are purchasing costs, ordering (set-up) costs, holding costs, shortage costs and system operating costs. Inventories are meant for satisfying the demand as it occurs and hence there is a trade-off between the benefits and cost of carrying inventories. The ultimate goal is to maximize the benefits while minimizing the cost.

This unit is devoted to work-in-process (WIP) inventory. The trend of WIP inventories are not so obvious as the raw materials inventory or the finished goods inventory and it is not easily visible as to what is unnecessary and what can be avoided. These things are usually hidden and needs to be properly identified first.

11.4 FACTORS INFLUENCING WIP INVENTORIES

Manufacturers today face many challenges and are in continuous pursuit to improve the effectiveness of their operations and the quality of their products by creating ways to remain responsive and competitive in the marketplace. Four "Ws" of product: who, what, when and where to make and ship to satisfy customer requirements are crucial in production. A significant portion of a manufacturer's financial resources are involved in inventories stored at various points in the supply chain. This is because of create buffer demand and supply variability, including raw materials and work-in-process (WIP) as well as finished goods.

It is necessary to pinpoint the factors and reasons for existence of WIP inventories. A flow process can be prepared to trace the flow of materials from the start to the finish. By this method you can find the delays that occurs in the course of production process. If the materials are held up in the production process, then the other factor that could affect WIP could be storage space and the consequent storage costs and inventory carrying costs. There would be inventory-handling costs also that will go up as the material help up will have to be shifted to a temporary location and then shifted back into the line. These costs are non-value added costs as far as the product is concerned but, are to borne by the customer. If the production process is halted, it results in delayed material lying on the production floor rather than getting converted into a finished product. This halts the cash flow of the organization and hence is nonbeneficial for the organization. One must control WIP inventories by minimizing the overall production time.

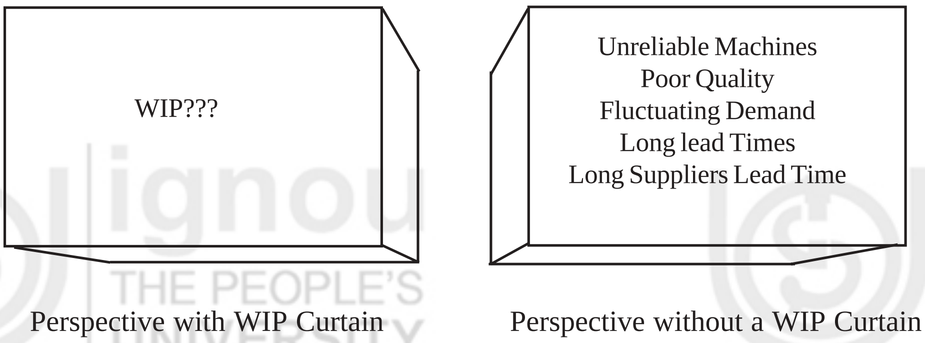

Figure 11.2: Perspective of an organization with or without WIP inventory

Figure 11.2 reveal that WIP inventories hide many bottleneck of an organization. It acts as a protective buffer against the bottlenecks. So if an organization is facing problems like having unreliable machines, poor quality, having fluctuating demands and higher lead times, it is bound to maintain a high level of WIP inventories.

Shah (1996) mentioned some factors that contribute for WIP inventories. They are as follows:

- These materials remain in the inventory as protective buffer against production breakdown or rejection.
- These materials remain in the inventory for economic lot production i.e. a larger quantity is sometimes produced than what is actually required.
- These materials remain in the inventory, as sometimes they have to wait for matching components and other materials for final assembly.
- These materials remain in the inventory due to the delay in the next stage of production.

An effective way to control WIP inventories is effective planning and coordination of production activities. The amount of WIP inventory is directly dependent on the length of the production cycle, the percentage of machine utilization, the "make or buy" policies of the organization and the management policy. The amount of WIP inventory depends on the type of production job. The table below summarizes the effects of different types of production jobs on the WIP inventories:

Table 11.2: Different types of production jobs & WIP inventory

S.No	Type of Production Jobs	Description	WIP inventory
1	*Flow Production*	Manufacture is continuous and proceeds as a balanced flow from one operations to another and one machine to another. No queuing between work centers.	WIP depends on the cycle time. Little scope for its reduction.
2	*Batch Production*	Quantity produced in a batch has to be stored for further use at a different time.	WIP inventory can be reduced substantially.
3	*Job Production*	Production is undertaken to meet specific customer demand.	WIP inventory is generally small.

Source: Based on Shah (1996), An Integrated Concept of Materials Management

11.5 METHODS OF CONTROLLING WIP INVENTORIES

There are many methods of controlling WIP inventories. If an organization is producing some product then some material must lie on the shop floor in various intermediate stages, but surely it can be minimized. Let us discuss some of these methods.

1) **Manufacturing Cycle Efficiency:** Proper production planning and control is necessary to make sure that there is a smooth flow of work and hence no detainments in any stage of production. Manufacturing cycle efficiency is the ratio of total permissible time for all productive operations and the elapsed time. This ratio is unity if the efficiency is perfect. It means that if total permissible time for a work is 2 hours then it is actually finished in that time. A ratio of 0.5 would mean that if total permissible time for a work is 2 hours then it is actually finished in 4 hours. Many organizations maintain very high WIP inventories because their manufacturing cycle efficiency is as low 0.1 or 0.2. To reduce WIP, one should aspire for maximum efficiency on this count.

2) **Work Center Efficiency:** Work Center Efficiency is another ratio used by many organizations. It is the ratio of time spent on a job at the work center to the permissible time. A high ratio indicates that the wok center is not working properly. Again the ideal ratio is unity indicating that the work is finished in perfect manner.

3) **Pull Systems and Kanban:** You have studied about pull systems earlier in this course in unit 9. Let us discuss about them in light of WIP inventories once again. Pull systems originated from a production control techniques developed by Toyota Motor Company, Japan in 1960. It provides a simple production control technique that reduces lead-time and work-in-process inventories. Kanban is the tool originally used to achieve these objectives. According to Sipper et al. (1998), "A push system controls work release orders, whereas a pull system controls the shop floor". To be more specific, push systems controls throughput (by controlling work release) and measure WIP, whereas pull systems control WIP and measure throughput (Spearman, 1992)". The pull technique is often called Just-in-time (JIT) or integrated JIT system.

The basic objective of the pull system is to produce the right components/ subassemblies needed, at the time needed, and in the quantities needed, or that the right component/subassembly should be at the right place at the right time. The primary goal is the elimination of all kinds of waste in the production system. Inventory is also a source of waste, since there is no value added by allowing the accumulation of inventory between work centers. Thus if one gets the component/ subassembly to the next work center just in time for the next step of production, then the inventory between the production stages is reduced. The attainment of this objective of minimizing the stock accumulation between successive manufacturing is enabled fundamentally by action on two fronts, namely, redesign of production methods, and use of an information system for production scheduling supported by the kanban technique.

Instead of pushing a lot/batch of completed (processed components/subassemblies) to the next work center, the pull system adopts a reverse method in which the following work center, or operation, withdraws the components/subassemblies from the preceding work center, or operation. To understand the reason for this, let us consider our example of production of an automobile. In this case where the end product of the company is an assembled car, only the final assembly line is the work center, which knows the exact timing (of receipt) and quantity of the required parts (in this case, major assemblies like engine, transmission, suspension etc.). Therefore, the final assembly line instructs the preceding work center to supply the necessary parts, or in other words, it goes to the preceding work center to obtain the necessary parts. The preceding work center then produces the parts withdrawn by the following work center (the final assembly line, in this case). Similarly, for the production of these parts, the preceding work center obtains the necessary parts from the work center preceding it, and so on.

You will realize that this simple method of production scheduling can only be achieved if the production methods are redesigned to ensure smoothened unhindered production in which the parts (or components and subassemblies) are manufactured quickly and with the minimum amount of non-productive time on account of in-process waiting and set-up, a balanced production system in which all jobs (operations) are finished within the cycle time, and multi-skilled workers and flexible facilities. Such a production system can achieve a smooth, synchronized flow of small lots of parts at a uniform rate.

Kanban is the Japanese word for 'card' or 'signal'. Kanban system is a system of scheduling based on the pull system and uses kanbans, or cards, sent from a downstream operation to trigger production (or supply) at an upstream operation (or by the supplier). As noted earlier, JIT is often considered synonymous with this system, and that this system requires a stable, repetitive manufacturing environment. The pull system looks at the manufacturing process from the perspective of the finished (or end) product. The production controller works on the basis that his/her orders, which represent firm customer requirements. The controller checks whether sufficient components and/or sub-assemblies/assemblies are available at the highest level of the product structure, as for example on the final assembly line, to produce the finished product. If they are, the product is produced. However, if they are not, the necessary components and/or subassemblies/assemblies are pulled from the preceding work center. A similar procedure is followed right back through each production stage, and extending all the way back to include outside vendors.

The kanban system generally uses two kanbans, or cards, namely, the move and production kanbans. The kanban system focuses on making only what is needed to replace components and/or subassemblies soon after they are used. The use of subassemblies from their container* triggers the issue and delivery of the move card on that container to the source work center's IN station. The removal of a container (with components or subassemblies) from its OUT station (and the transportation of the container to the IN station of the succeeding work center) releases a production card to the source work center, and another lot of components is produced to fill one container. This is delivered to the OUT station when completed, usually within one to three days. The use of components in this work center's IN station to make the lot, in turn, triggers move cards and production cards in upstream work centers. In this manner, all production in the work centers is geared to making only what is required.

Kanbans, or cards, constitute a simple and flexible system of scheduling that promotes close coordination among work centers in repetitive manufacturing. The amount of material in the system is controlled by having a prescribed number of containers in circulation at any time. A user work center 'pulls' containers from a supplier work center with a move card. Thus, a supplier work center cannot 'push' a container out to a user work center until the user is ready, and its readiness is indicated by the arrival of the move card. Moreover, the supplier work center cannot produce until it receives a go-ahead in the form of a production card.

There are clearly some limitations to the kanban system. Kanban is intrinsically a system for repetitive manufacturing. Also, since each daily assembly schedule must be very similar to all other daily schedules, it becomes essential to be able to freeze

* Each item-component or subassembly – has its own container, and the container contains the required number of the component/subassembly.

the MPS for a fixed time period, generally at least one month. The final assembly schedule must, thus, be very level and stable. Kanban will not succeed without modification in a batch production (non-repetitive manufacturing) environment. It requires a leveled schedule, standard containers and very strict discipline. It may be considered inflexible in that it cannot easily respond to irregular changes (in the MPS) and to large unexpected changes in market demand. Also, the implementation of kanban scheduling requires great cooperation from outside suppliers (recall supplier's flexibility in the definition). Moreover, from the perspective of the manufacturing process, it places emphases on process technologies, such as product-based flow configurations, and may, therefore, require considerable investment of time and money in developing new production methods, procedures, jigs, fixtures, etc. and perhaps even new capital equipment.

However, if well implemented, kanban stimulates productivity improvement, reduces inventory and manufacturing lead-time, and within the constraints of the product design and manufacturing system design, allows the plant to respond to predictable small market variations. Moreover, kanban is a simple system of flow control with a visible means of inventory control. It is simple to understand and involves very little paper work as compared to a typical MRP system.

Activity 1

"Certain elements of JIT, like JIT purchasing, can be incorporated in a batch production environment using MRP II, and MRP with JIT may be quite useful and effective in bringing down inventory levels, particularly WIP inventory". State the reasons behind this.

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4) **CONWIP Models:** Spearman (1990) introduced the concept of CONWIP, which means "constant work-in-process". It is an approach to pull systems. A CONWIP system can be described by taking an example of a single production line. Let us assume that the parts are moved in containers holding the same amount of work. Thus, the processing time at each workstation, including a bottleneck is the same. A card is attached to the container at the beginning of the line to act as an information signal. Card is removed at the end of the line and is returned to a card queue at the beginning of the line and waits for another container to pass through the production line again.

   In a CONWIP system the card goes across a circuit that includes the whole production line unlike kanban were the loop go across the next work center downstream. In CONWIP line, production cards are assigned to the line rather than a specific product. CONWIP systems use kanban and a schedule. The backlog list shown in the figure decides what goes in the line and is generated from the master production schedule. The card decides when a container will go in the line. CONWIP is a mixture of "pull" and "push" systems. In CONWIP system the backlog list triggers the push system that initiates production in anticipation of a future demand while pull system takes care of the present demand. CONWIP systems handle those production lines better, which produces many parts.

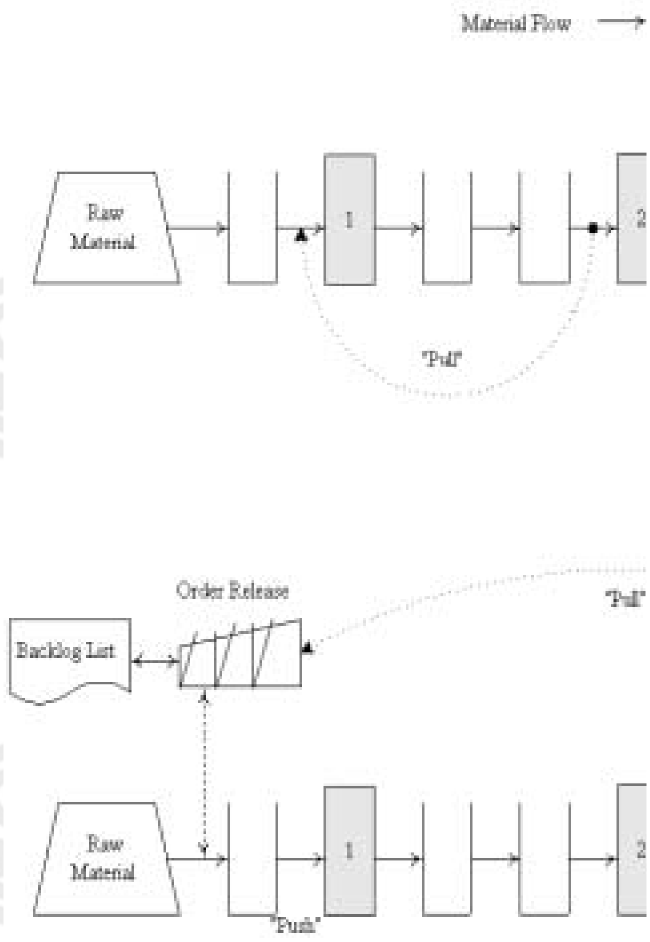

Figure 11.3: Comparison of Kanban and CONWIP Systems

Source: Sipper et al (1998), "Production: Planning, Control and Integration

The Figure 11.3 displays this comparison between a CONWIP system (at the bottom) and a kanban system (at the top). Spearman et al (1992) proved that CONWIP is a self-regulating system and results in lower WIP levels than a kanban system. CONWIP is best suited for organizations operating their production lines near capacity. CONWIP is also considered applicable to production environments characterized by longer set-ups and fluctuating demand. A major benefit of a CONWIP is the low variability of the flow time.

5) **PERT & CPM:** A variety of parts and component go into the production cycle at various stages of the production process. Some of the production processes are simultaneous. CPM & PERT can be used to reduce the production cycle time and in turn save on WIP inventories. Let us discuss some tools and techniques that are vital in effective planning, scheduling and control of projects. You have read them in detail in the course MS 52: Project Management.

   Network diagrams provide a mechanism to depict the interdependencies of various activities that constitute a project. An activity is a homogeneous element of work consuming some resources and requiring some definite amount of time for its completion. The starting of an activity or the ending of an activity is called an event. A project is completed only when all its activities have been completed. It becomes important to identify which activity may be going on simultaneously and which other have to be done one after the other. As simple event is one, which has only one preceding activity, and only one succeeding activity. A merge event is one, which has more than one preceding activities and only one succeeding activity. A burst event is one, which has only one preceding activity and more than one succeeding activities. An event having more than one preceding activities as well as more than one succeeding activities is a combined merge and burst event. To show the activity interdependency explicitly we need to introduce dummy activities that do not consume any resource or time for its completion. The basic requirement for drawing of networks has two components, viz, a list of individual activities and activity interdependencies.

Time analysis of networks gives us insight into the project and its activities. In forward pass we begin with the starting activity or the starting activities of the project and gradually move to their respective succeeding activities i.e. move forward in time. For each activity Early Start (ES) and Early finish (EF) is worked out, relative to the zero-date of the project. In a backward pass, for each activity Late Finish (LF) and Late Start (LS) time is worked out. Here it is given that the completion of the project must be achieved by a certain date. One moves to the immediate predecessors and do the same time calculations. The process thus begins with the finishing activities and continues through their predecessors till we reach the start of the project. We move backwards in time in this case.

Activity slacks or looseness of some activities are calculated. Total slack for an activity is the difference between its LF and EF or that between its LS and ES. Free slack can be calculated as a difference between the ES of a succeeding activity and EF of that activity. Independent slack is calculated by subtracting LF of a preceding activity and estimated duration of that activity from the ES of a succeeding activity.

If project has to be finished at its earliest completion then some activities cannot be delayed at all. These are the activities with zero slack and they are called critical activities, as their timely completion is critically important for the timely completion of the project. The critical path is also the longest path from the start of the project to its finish. A project may have more than one critical path. While a project is under execution critical activities need to be monitored very closely as any delay in their completion is immediately reflected as a delay in the project completion.

In many projects there are activities whose time durations cannot be estimated very precisely because of the high degree of uncertainty associated with them. In fact, it may become impossible to get satisfactory time estimates for some activities because of uncertainty in their durations. In Program Evaluation and Review Technique (PERT), a special mechanism has been developed to handle these uncertainties. For some activities were the degree of uncertainty is high, it may be easier and more appropriate to get three different time estimates for each activity duration rather than trying for the best estimate. If all conditions are favorable then the minimum time in which an activity can be finished is called the optimistic time (a) of that activity. If all the conditions are unfavorable then the maximum time in which an activity can be finished is called the pessimistic time (b). In reality some factors may be favorable and some unfavorable so the actual time in which an activity can be finished will like somewhere between optimistic time and pessimistic time. Most likely time (m) is that duration of the activity, which has the highest probability of occurrence among all possible values of the activity duration. It is empirically known that the probability density function of activity duration closely follows a Beta distribution. The expected duration of the activity and its standard deviation is calculated as shown below:

Expected duration of an activity, $t = \frac{a + 4m + b}{6}$

Standard deviation of activity duration, $\sigma = \frac{b - a}{6}$

A path on a project network diagram is simply a sequence of activities and the path length (or duration) is nothing but the sum of the durations of all the activities on the path. If the various activity durations are independent of each other, then the expected duration of a path is the sum of the expected durations of all the activities on the path and the variance of the path duration is the sum of variance of all the activities on the path. Applying central limit theorem we can find the expected duration of any path and also its variance and shape. The longest expected duration path is called the critical path. The probability of the critical path can be taken as the probability of the completion of the project.

Apart from activities-on-arrows (AOA) diagrams, there are other diagrams also like activity-on-node (AON) diagrams and precedence network diagrams to represent activity interdependencies.

As far as project scheduling is concerned ES schedule and LS schedule are viewed as the limits between which the actual schedule must lie else the project will be delayed. In resource scheduling, time analysis may not produce a feasible schedule because resource availability constraints are not considered there. We must identify resource conflicts i.e., periods where current schedule requires more resources then available and try to remove resource conflicts to get a feasible schedule. If a conflict is identified then its removal may have many consequences on the project duration.

The steps involved in project planning and scheduling could be summarized as follows:

- Establishing the project goals and objectives
- Defining the wok- i.e. breaking the project into constituent activities
- Estimating the activity duration and defining activity interdependencies
- Carrying out time analysis of the project
- Establishing the resource availability and requirements
- Developing a resource feasible schedule
- Analyzing activities to find feasibility of crashing
- Optimizing the baseline plan and schedule
- Freezing the baseline plan and schedule.

6) **Operations Research Models:** Materials are nonrenewable resources. Inventory of materials is formed because of a disparity in quantity and timing between supply and demand. This difference can be caused by four factors: economies of scale, operation smoothing, customer service and uncertainty. If you have to control inventories then you have to control these four factors. Operations Research techniques play a vital role here.

Table 11.3: Use of OR Techniques

S.No.	OR Technique	Use in Production Planning, Control & Integration
1	*Sensitivity analysis*	Aggregate planning, Assumptions in problem solving, Inventory problems
2	*Linear programming*	Aggregate planning, Bottleneck systems: Optimized production technology (OPT) and theory of constraints (TOC), Modeling of time/ cost trade-off
3	*Transportation problem*	Production planning problem with constant work force, Aggregate planning

4	*Integer programming*	Disaggregating plans problem,
5	*Dynamic programming/ Branch & Bound*	Scheduling problems e.g. scheduling a bottleneck machine, Resource leveling, Minimizing the variable inventory cost, ordering and holding cost, Inventory: periodic review problems,
6	*I/O analysis*	Finite-capacity planning
7	*Delphi Technique*	Forecasting
8	*Queuing theory*	CONWIP performance evaluation problems
9	*Traveling salesman problem*	Operations scheduling: minimizing setup times
10	*Simulation*	Feasibility of changes in master production schedule (MPS), Operations scheduling, JIT system description, Time-based material flow/ WIP inventories, Production-floor oriented packages, Comparison of Kanban and CONWIP

Table 11.3 shows some applications that might be helpful in production planning and control and eventually in reducing inventories. You have read many of these techniques in the course MS-51: Operations Research. They are merely listed here so as to arouse your interest.

Activity 2

Search the Internet and try to find examples of application of OR models in production planning and control.

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11.6 SUMMARY

Process inventory is the inventory of goods that are an essential part of the production process. They are concerned with the materials or semi-finished goods on the production floor. These materials are essentially an integral part of the total production process. There are many integrated production systems designs like cellular manufacturing systems (CMS); flexible manufacturing systems (FMS) and computer integrated manufacturing (CIM) that gives high importance to reduced work in process. FMS in particular is more concerned about WIP as it mainly deals with the production floor. It is necessary to pinpoint the factors and reasons for existence of WIP inventories as if an organization is facing problems like having unreliable machines, poor quality, having fluctuating demands and higher lead times, it is bound to maintain a high level of WIP inventories. There are many methods of controlling WIP inventories. If an organization is producing some product then some material must lie on the shop floor in various intermediate stages, but surely it can be minimized. The unit discusses some of these methods.

11.7 SELF ASSESSMENT QUESTIONS

1) What is wrong with having high levels of WIP inventory? Is it possible to operate manufacturing system with almost no WIP at all? Why?
2) "If you reduce WIP then you expose many organizational bottlenecks". Comment on this statement. Also, state the reasons for your agreement/ disagreement.
3) CONWIP is considered applicable to production environments characterized by longer set-ups and fluctuating demand. Why?
4) State the role of backlog list in a CONWIP system. What is the trigger or releasing jobs in to production in a CONWIP based production line?
5) Discuss the role of PERT/CPM in controlling the WIP inventories.
6) Why it is said that a process inventory is the inventory of goods that are an essential part of the production process.
7) How is customer affected if a company is maintaining a higher level of WIP?
8) "A push system controls work release orders, whereas a pull system controls the shop floor. To be more specific, push systems controls throughput (by controlling work release) and measure WIP, whereas pull systems control WIP and measure throughput". Comment

11.8 REFERENCES AND SUGGESTED FURTHER READINGS

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