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PRODUCTION AND INVENTORY MANAGEMENT



THANWADEE CHINDA

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Chapter 1

Introduction to Production and Inventory Management

This chapter includes the following topics:

- What is production management?
- What is inventory management?
- Uncertainties in production and inventory management
- What is covered in this textbook?

1.1 What is Production Management?

Production and operations management is the set of activities that creates value in the form of goods and services by transforming inputs into outputs. According to ME Mechanical (2018), production management deals with decision making related to production processes so that the resulting goods or services are produced according to specifications, in the amount and by the schedule demanded, and out of minimum cost. Activities creating goods and services take place in all organizations, both manufacturing and service industries. In the manufacturing industry, product is tangible. In the service industry, however, product is intangible, and may take such forms as the transfer of funds from savings to checking accounts, the reservation of the tables in the restaurants, and the classes provided to the students.

To create goods and services, every organization must perform three functions, as follows:

- Marketing: This function generates demand or orders for a product or service. This demand is used to develop sales and operations and other production plans for the company.
- Production: This function creates the product. A number of constraints must be considered when planning for a production, such as waiting time and bottleneck work centers.
- Finance/accounting: This function tracks how well, in financial term, an organization is performing.

Production management aims to produce goods and services of right quality and right quantity at the right time and right manufacturing cost.

- Right quality: The quality of the product is established based on the customer needs in the market. The right quality is not necessarily the best quality of the product. It is rather determined by the cost of the product and the technical characteristics as suited to the specific requirements of the customers in the market environment.
- Right quantity: The manufacturing organization should produce the products in the right quantity. Overproduction results in the capital blocked up in the form of inventory; underproduction, on the other hand, leads to a shortage of products.
- Right time: Timeliness of product delivery is one of the critical parameters to judge the effectiveness of the production department.
- Right manufacturing cost: Manufacturing costs incur before the products are manufactured and released into the market. Hence, all attempts should be made to produce the products at a pre-established or standard cost, and avoid any unforeseen costs.

There are a number of functions performed in the production management, including

- Design and development of the production process,
- Production planning and control,
- Implementation of the plan and related activities to produce the desired output,
- Administration and coordination of the activities of various components and departments responsible for producing the necessary goods and services,
- Get real-time insight into the production,
- Improve performance with flexible routing, and
- Monitor production costs with ease (MBA TUTS, 2017).

1.2 What is Inventory Management?

Inventories are items accumulated for sales, in the process of manufacturing, or in the form of materials yet to be utilized. An inventory system is the set of policies and controls that monitor levels of stocks, and determine what levels should be maintained, when the stocks should be replenished, and how large the orders should be. The inventory management, therefore, is defined as the system used by a firm to control its investment in inventory. It involves the recording and monitoring of stock levels, forecasting future demand, and deciding on when and how to order. The primary goal of inventory management is to have adequate quantities of high quality items available to serve customer needs, while also minimize the carrying inventory cost (John et al., 2015). Companies can reduce costs by reducing the inventory; however, this may create stock out, resulting in customer dissatisfaction. On the other hand, an overstock can be a potential source of waste, if it is expired or outdated.

An effective inventory management requires such information as machine capacity, ordering amount, supplier availability, delivery time, bottleneck work center, and customer demand. Having an effective inventory management assists the company in 1) avoiding product spoilage, especially those with short life cycles, 2) avoiding dead stock (i.e. stock that can no longer be sold for various reasons, such as out of season and out of style), and 3) saving on storage costs. In addition, an effective inventory management improves cash flow, as shown in Example 1.1.


Example 1.1 An effective inventory management improves cash flow.

Jade Company, a furniture manufacturer in Pathumthani, has the following income statement:

Sales	\$6,000,000
Cost of goods sold	\$3,300,000
General administrative expenses	\$1,206,000
Marketing expenses	\$1,050,000
Net income before taxes	\$444,000

This results in the return on sales of 7.4% (i.e. $444000/6000000$). If the company improves the inventory management, this might reduce the cost of goods sold by 2%, thus reducing general administrative expenses by 1% through the reduction of storage and insurance costs. These result in:

Sales	\$6,000,000
Cost of goods sold	\$3,234,000
General administrative expense	\$1,193,940
Marketing expenses	\$1,050,000
Net income before taxes	\$522,060

With small cost reduction through an effective inventory management, the company now receives 8.7% in the return on sales, 17.6% higher than the previous percentage.

1.3 Uncertainties in Production and Inventory Management

Any uncertainties in production and inventory management can cause severe results. A case study of inventory management of petroleum products in Thailand in 2014 revealed that the uncertainties induce businesses to hold more of the inventory-to-sale ratio than required (see Figure 1.1). The uncertainty in the ex-refinery price contributes mostly to the uncertainty in the inventory management, while the impact

Estimated uncertainty in inventory management (%)

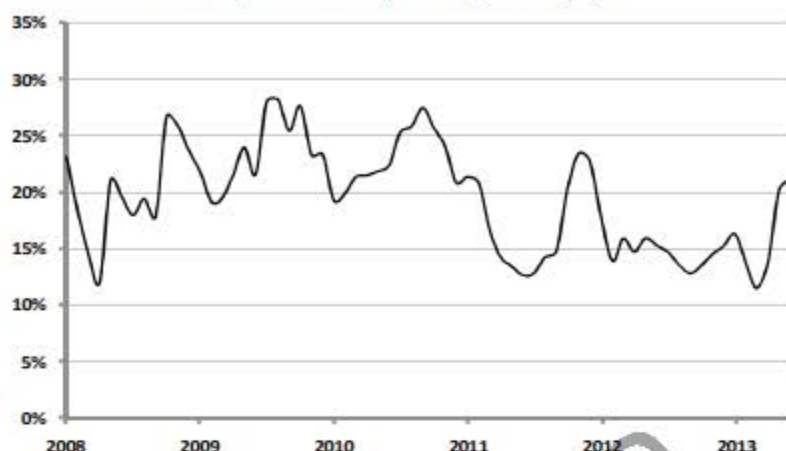


Figure 1.1 Case study of estimated uncertainty in inventory management (Roekchamnong et al., 2014)

of uncertainty in the oil fund on the uncertainty in the inventory management is relatively small. The results also indicate that uncertainty in future prices can help mitigate the uncertainty in the inventory management, and gives support to the existence of the future markets (Roekchamnong et al., 2014).

Another case study attempts to design an inventory management system for motorcycle parts to control inventory of raw materials (see Figure 1.2). Make-to-stock production is currently used, with the order amount based mainly on entrepreneur's decision. This, however, results in an overstock. The inventory management system is then developed to decide whether an order for the inventory should be made. With this inventory management system, the company can keep track of flows of products and supplies, and reduce total inventory cost.



Figure 1.2 Examples of motorcycle parts (Treerattrakoon and Lersbuasin, 2015)

1.4 What is Covered in this Textbook?

This textbook looks at production and inventory management in various perspectives. It is organized into 11 chapters, as the followings.

- Chapter 1: Introduction to Production and Inventory Management. This chapter overviews the production management, inventory management, and uncertainties in production and inventory management.

- Chapter 2: Sales and Operations Plan (S&OP). This chapter details fundamentals of the S&OP. Different strategies used to develop the S&OP are presented, such as chasing strategy, leveling strategy, and mixed strategy.

- Chapter 3: Master Production Scheduling (MPS). This chapter considers the MPS in different production environments. Details of an MPS, including forecast demand, orders booked, ending inventory, available-to-promise, lot sizing decision, and safety stock are described in details. Managing the MPS in a dynamic environment utilizing freezing period is also discussed.

- Chapter 4: Material Requirements Planning (MRP). This chapter details key information in an MRP, including bill of materials and backward scheduling. The chapter also discusses key data used in an MRP record, including gross requirement, scheduled receipt, ending inventory, net requirement, planned receipt, and planned order. An updated MRP, when changes occur, is also presented.

- Chapter 5: Distribution Requirements Planning (DRP). This chapter considers DRP in the supply chain, and relationships between the MPS, MRP and DRP.

- Chapter 6: Capacity Planning. This chapter introduces short-, medium-, and long-term capacity plans. A number of capacity techniques, including capacity planning using overall factors, capacity bills, resource profiles, and capacity requirements planning are considered in capacity management.

- Chapter 7: Inventory Management. This chapter utilizes an and a cycle counting approach to manage inventory. To determine an ordering amount, a number of inventory models are introduced, such as economic order quantity and discounting. Reorder point and safety stock are, on the other hand, presented to determine the lead-time or ordering period necessary to avoid the stock out.

- Chapter 8: Inventory Management: Managing Uncertainties. This chapter presents indices, service level, and average inventory used to measure inventory performance. The chapter also focuses on inventory management when demand and performance cycle time are uncertain. Different policies to manage inventory are also discussed.
- Chapter 9: Theory of Constraints (TOC). This chapter explains various TOC concepts. Group scheduling and transfer batches are introduced to manage with bottleneck work centers. The TOC scheduling is also developed using processing time and workload schedules.
- Chapter 10: Waiting Line Theory. This chapter explains cost of waiting and cost of service in the waiting line theory. Different characteristics of a waiting line system are presented.
- Chapter 11: Lean Operations. This chapter discusses advantages of lean production. Various lean perspectives are pinpointed. Kanban system and Poka Yoke technique, which are the approaches in the lean production, are also discussed in details.

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Chapter 2

Sales and Operations Plan

This chapter includes the following topics:

- What is sales and operations plan (S&OP)?
- Fundamentals of the S&OP
- The S&OP strategies
- Issues concerned with the S&OP
- Case studies

2.1 What is Sales and Operations Plan (S&OP)?

Sales and Operations Plan (S&OP) is an important step of any productions. It considers an aggregate level of manufacturing of various products, and integrates various functions in the company (see Figure 2.1). S&OP links strategic goals to production, and coordinates various planning efforts in a business, including marketing, financial, production, human resources, and management functions. For instance, the marketing department launches a new product in the market. This is added in the S&OP so that the financial department can coordinate in increasing manufacturing capacity and building up the inventories to support the marketing promotional plans. The human resources department is, on the other hand, required to obtain more staff to support with the production of the new product. These confirm the importance of the S&OP for a success of the business.



Figure 2.1 Linkages in the S&OP (Jacob et al., 2011)

S&OP proves to be an effective tool for any company. It gives executives a comprehensive overview of the business so they can grasp where it stands. This allows them to continuously match high-level strategy with day-to-day operational tactics in all departments. Below are comments from various managers.

- *Suresh Dalai*, a retail operations professional based in Singapore, has been implementing S&OP best practices for more than 20 years in Asia and the U.S. with retailers, such as Levi Strauss and Ermenegildo Zegna. He suggests focusing on people, process, and practice:

- ▷ People: “ensure that the implementation is heavily cross-functional and that different functions are bringing different perspectives to the table. Ensure that people are engaged in the process by clarifying roles and accountabilities, fostering an environment for open discussions, and helping people understand that their most important role is in making sure that you smoothly hand off your finished product to the next person in the process.”
- ▷ Process: “clearly define the end-to-end process steps, and delineate who is responsible, accountable, consulted, and informed. Also, develop a calendar so that activities are done timely, and make sure someone is facilitating that calendar.”
- ▷ Practice: “make sure people understand that a well-executed S&OP process does not happen overnight, that it takes practice, and that it is OK to make mistakes along the way. Instilling a culture of continuous improvement is a key.”

- *Kyle Brost*, principal of the Choice Group, offers three S&OP tips:
 - ▷ First, make sure diverse groups of people across the organization are able to participate in the process. S&OP is not just about balancing supply with demand; it is about aligning the organization. Without including people from across the organization, it is easy to end up with a great plan that never be executed.
 - ▷ Second, if alignment is a key component of S&OP, there has to be something to align to, and this should be the high-level strategy for the organization. Effective S&OP is not a stand-alone effort; it really is the bridge between the strategy of the organization and operational execution. When strategy and S&OP are disconnected, you end up executing perfectly on all the wrong things.
 - ▷ Third, as part of the plan, try to assume and predict where it will fail and build mitigation plans. This way, when challenges to the plan surface, the organization is not caught off guard. Rather, they anticipate them, and know what to do about them.
- *Jeffrey J. Fox*, founder of management consulting firm Fox and Company, gives three tips for cross-department sales planning processes:
 - ▷ Never lose sight that the goal is to increase profitable revenues. Too many companies morph this planning process into a new department, a new set of procedures, bureaucratic stuff that strangles selling.
 - ▷ Cross selling between business units is hard for lots of reasons. Everyone who is not in the field thinks it is easy. There are many legitimate barriers. Do not expect a person in Unit A to sell products made by Unit B. That is never going to happen. Incentives must be such that the person in Unit A is encouraged to get his customer to buy something from Unit B. This incentive can be a finder's fee, a referral fee, or something else. In addition, Unit B has to teach Unit A, not how to sell, but how to recognize opportunities for Unit B (and vice-versa).
 - ▷ One good objective is to design a product forecasting system that overlays Units A and B. Forecasting is tough, but doable. A good forecasting model helps balance inventory, directs supply chain managers, and affects sales

compensation. A good management technique is to establish a three-month task force to get it done, and include salespeople on the task force. If it goes past three months, it is doomed.

- *Ali Mirza*, president of Rose Garden Consulting, offers below advices:
 - ▷ Make sure different departments are speaking the same local language. Take the time to be clear. Many times, they are using terms differently.
 - ▷ To do a good sales forecast, account for changing circumstances. Historical data needs to be placed in the context of what is happening now. At a smaller company, a top seller's personal problem, such as a divorce, could even have a large impact.

2.2 Fundamentals of the S&OP

There are four fundamentals in the S&OP, including 1) demand, 2) supply, 3) volume, and 4) mix, see Figure 2.2 (Jacob et al., 2011). There is a need to balance the demand and supply. When demand exceeds supply, customer suffers from cost increases, as overtime working and premium freight rates are added in the price. Poor quality products could also occur from a rush production. An example of the demand over supply was in 2011 when Thailand faced severe flooding. Demand of boats became massive, resulting in the price increase by almost five times.

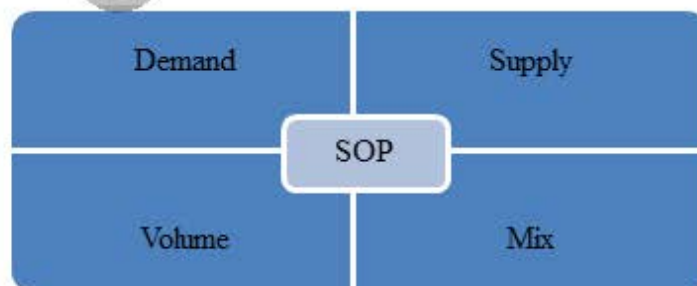


Figure 2.2 Fundamentals of the S&OP (Jacob et al., 2011)

On the other hand, when supply exceeds demand, manufacturer suffers from price cuts and inventory buildup. Layoff is unavoidable, resulting in decrease in plant efficiency. An example of the supply over demand can be seen from coffee and tea stalls

all around Thailand. When there are too many shops in the same area, customers reduce, resulting in layoff and business closed.

With a proper S&OP, an effective coordination between the functions, together with top management commitment, can be achieved, leading to the balance in demand and supply, and most favorable profit of the company.

Apart from the demand and supply, the volume and mix are also crucial in S&OP development. The volume fundamental concerns with the amount of production to be produced and the stock to be kept, while the mix fundamental considers detailed production of each product in terms of sequences and number of customers. To explain, volume links the production plan of the company in a whole year, while mix considers the production of different products from different customers. Mix fundamental, therefore, requires a more careful production plan to maintain customer satisfaction.

In summary, the role of S&OP is to balance the demand and supply, at the volume level that can accommodate the mix production and satisfy the customers.

2.3 S&OP Strategies

To develop the S&OP strategy, several important inputs are required, including the sales forecast (in terms of units or dollars), the operations plan (in terms of units or a number of workers required), the inventory plan (in terms of units, dollars, or days of supply), and the actual operating results from the past periods (in terms of units or dollars). Additional information may include the employee productivity, hiring and layoff costs, inventory carrying cost, number of working days/month, on-hand inventory, and beginning workforce.

A number of strategies can be used to develop the S&OP. Three common methods, including the chasing, leveling, and mixed strategies are listed here.

2.3.1 Chasing Strategy

This S&OP strategy aims to balance the demand with supply. The manufacturer produces exactly the amount required by customers each month, and keeps no inventory at the end of the plan. The fixed amount of ending inventory can, however, be considered with this strategy, if needed. Example 2.1 shows an example of a chasing strategy of a

12-month plan. In this plan, the operation is set to chase the forecast sales each month. Changing production output, however, may incur hiring, layoff, overtime working, part time working, and subcontracting costs. If a part timer is needed, a maximum working hours/part timer/day is 4 hours in this strategy. Calculation of each input is as the followings.

- *Forecast sales* report the expected demand month-by-month. This information can be retrieved from historical data, or from calculation using a number of forecasting techniques, such as exponential smoothing, weighted moving average, and trend projection methods.

- An *average daily forecast sales* is achieved by dividing the forecast amount by a number of working days in a month. For example, an average daily forecast sales of month 1 is $253,000/20=12,650$ units/day.

- *Operations plan* is set to match the forecast sales in each month. For instance, a forecast sales of 253,000 units becomes an operations plan of 253,000 units in month 1.

- An *average daily operations plan* is achieved by dividing an operations plan amount by the number of working days in a month. For example, an average daily operations plan of month 1 is $253,000/20=12,650$ units/day.

- The *number of workers required* is achieved by dividing an average daily operations plan by the labor productivity. Labor productivity represents the amount of output an employee can make in a day. Assuming a labor productivity of eight units/8-hour working day, this brings a number of workers in month 1 of $12,650/8= 1,581.25$ persons.

- This could result in 1,582 fulltime workers or 1,581 fulltime workers with a part timer working for $0.25 \times 8 = 2$ hours/day.

- Based on an operations plan that follows the forecast sales amount in this example, an actual ending inventory amount of 18,240 units in month 12 (history record) is to be kept as the *ending inventory plan* throughout the year. Assuming an inventory cost of \$0.50/unit/month, the inventory cost of $18,240 \times 0.50 = \$9,120$ is incurred every month.

Example 2.1

An example of a chasing strategy with a fixed amount of ending inventory

	History		Plan												Future	
	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month
	12	1	2	3	4	5	6	7	8	9	10	11	12	1		
Forecast sales (units)	210,000	253,000	280,000	340,000	300,000	391,600	220,000	285,000	420,000	280,000	128,000	527,000	393,000	267,000		
Average daily forecast sales (units)	10,500	12,650	14,000	13,600	15,000	17,800	10,000	19,000	17,500	14,000	6,400	26,350	19,650	13,350		
Actual sales (units)	200,000															
Operations plan (units)	220,000	253,000	280,000	340,000	300,000	391,600	220,000	285,000	420,000	280,000	128,000	527,000	393,000			
Average daily operations plan (units)	11,000	12,650	14,000	13,600	15,000	17,800	10,000	19,000	17,500	14,000	6,400	26,350	19,650			
Actual operations (units)	218,240															
Number of working days (days)	20	20	20	25	20	22	22	15	24	20	20	20	20	20		20
Number of workers required (persons)	1,364	1,581.25	1,750	1,700	1,875	2,225	1,250	2,375	2,187.50	1,750	800	3,293.75	2,456.25			
Number of fulltime workers (persons)	1,364	1,581	1,750	1,700	1,875	2,225	1,250	2,375	2,187	1,750	800	3,293	2,456			
Part-time working hours (hours/day)	-	2	-	-	-	-	-	-	4	-	-	6	2			
Number of part timers (persons)	-	1	-	-	-	-	-	-	1	-	-	2	1			
Ending inventory plan (units)	10,000	18,240	18,240	18,240	18,240	18,240	18,240	18,240	18,240	18,240	18,240	18,240	18,240			
Actual ending inventory (units)	18,240															
Days of supply (days)	1.44	0.30	1.34	1.22	1.02	1.82	0.96	1.04	1.30	2.85	0.69	0.93	1.37			
Fulltime hiring amount (persons)		217	169	-	175	350	-	1,125	-	-	-	2,493	-			
Fulltime layoff amount (persons)		-	-	50	-	-	975	-	188	437	950	-	837			

- *Day of supply* represents a number of days in the following month that the ending inventory in the current month can supply. To explain, the days of supply in month 1 is achieved by dividing an ending inventory plan amount of month 1 by an average daily forecast sales amount in month 2, which is $18,240/14,000=1.3$ days. In other words, an inventory amount of 18,240 units in month 1 is enough to supply the sales amount in month 2 for 1.3 days.

- Hiring cost incurs when the company posts an advertisement in newspapers and on online job platforms, or uses external advisors or placement agencies. Before making a final hiring decision, the company also needs to screen applications and invite a number of suitable job candidates for an interview. After signing a contract, new hires often need time to adapt to the specific environment of the company, resulting in the adaptation costs from a temporarily lower productivity (Muehlemann and Pfeifer, 2013).

- In this example, the *fulltime hiring amount* is calculated by subtracting number of workers in the current month with those in the previous month. Hiring amount in month 1 is, for instance, $1,581.25-1,364=217.25$ persons. If a hiring cost is assumed to be \$200/person, then the hiring cost in month 1 is $217.25 \times 200 = \$43,450$.

- Layoff can also be costly to the company as it generates various costs, such as costs associated with outplacement services, high employee turnover, low morale and labor productivity, and rehiring in cases of economic upturn (Iqbal and Akhigbe, 1997).

- In this example, the *fulltime layoff amount* is calculated by subtracting number of workers in a previous month with those in a current month. Layoff amount in month 3 is, for example, $1,750-1,700=50$ persons. If a layoff cost is assumed to be \$500/person, then the layoff cost in month 3 is $50 \times 500 = \$25,000$.

The operations plan amount in Example 2.1 increases and decreases following the forecast sales amount. This results in hiring and layoff cost. Moreover, an inaccurate forecast sales amount can result in inventory buildup, resulting in higher inventory cost. Focus, therefore, should be on ensuring an accurate forecast sales amount to achieve the lowest total cost.

With the cost table, as shown in Table 2.1, an estimate total cost of the S&OP in Example 2.1 can be calculated. It consists of fixed, variable, labor, part time working, inventory, hiring, and layoff costs.

Table 2.1 An example of a cost table

Input	Cost
Fixed cost	\$600/month
Variable cost	\$1.5/unit
Labor cost	\$1,000/worker/month
Part time working cost	\$3.5/hour
Overtime cost	\$7/hour in excess of normal working hours
Subcontracting cost	\$20/unit
Inventory cost	\$0.5/unit/month
Hiring cost	\$200/hired worker
Layoff cost	\$500/layoff worker

- Fixed cost of the 12-month period plan = $600 \times 12 = \$7,200$.
- Variable cost is based on the operations plans of the 12-month period i.e. $(253,000 + 280,000 + 340,000 + 300,000 + 391,600 + 220,000 + 285,000 + 420,000 + 280,000 + 128,000 + 527,000 + 393,000) \times 1.5 = \$5,726,400$.
- Labor cost is based on a number of fulltime workers in each month i.e. $(1,581 + 1,750 + 1,700 + 1,875 + 2,225 + 1,250 + 2,375 + 2,187 + 1,750 + 800 + 3,293 + 2,456) \times 1,000 = \$23,242,000$.
- Part timer cost is based on the part-time working hours in each month. For example, a part timer works for 2 hours/day in a 20-working day in month 1. This becomes the part timer cost of $2 \times 20 \times 3.5 = \140 . Total part timer cost is then $((2 \times 20) + (4 \times 24) + (6 \times 20) + (2 \times 20)) \times 3.5 = \$1,036$.
- As a total of 18,240 units are to be kept throughout the year, the total inventory cost for the 12-month plan is then $18,240 \times 12 \times 0.5 = \$109,440$.
- Fulltime hiring cost = $(217 + 169 + 175 + 350 + 1,125 + 2,493) \times 200 = \$905,800$.
- Fulltime layoff cost = $(50 + 975 + 188 + 437 + 950 + 837) \times 500 = \$1,718,500$.
- Total cost of this plan = \$31,710,376.

The total cost of the 12-month plan in Example 2.1 is \$31,710,376. It is found that the labor cost constitutes 73.3% of the total cost. Production managers should, therefore, ensure that high labor productivity is attained to avoid extra labor costs. Apart from the labor cost, the layoff and hiring costs constitute almost 10% of the total cost. The chasing strategy, therefore, might not be suitable when the hiring and layoff costs are high.

2.3.2 Leveling Strategy

Leveling strategy keeps constant workforce for the entire planning period. This results in inventory buildups when cumulative production is greater than cumulative demand, and backorder cost when the opposite is true.

Example 2.2 shows an example of a leveling strategy by keeping a constant number of workers of 1,915 persons/month, and having no inventory at the end of the plan. A constant number of workers of 1,915 persons each month is calculated by summing the forecast sales amount of the 12-month plan, and deducting with the actual on-hand inventory to achieve the net demand over the 12-month period. This net demand is then divided by the total working days in a year and the labor productivity to achieve the number of workers required.

- With a labor productivity of 8 units/day and an actual on-hand inventory (i.e. inventory in month 12 last year) of 18,240 units, a number of workers required each month in this example are:

Total forecast sales amount = $253,000+280,000+340,000+300,000+391,600+220,000+285,000+420,000+280,000+128,000+527,000+393,000=3,817,600$ units

Net demand = $3,817,600-18,240=3,799,360$ units

Total working days = $20+20+25+20+22+22+15+24+20+20+20+20=248$ days

Number of workers required = $3,799,360/(248 \times 8)=1,915$ persons

- *Operations plan* is calculated based on the number of workers. For example, operations plan in month 1 is $1,915 \times 8 \times 20= 306,400$ units (assuming the labor productivity of eight units/day with a 20-working day in month 1).

Example 2.2

An example of a leveling strategy with a constant number of workers each month

	History	Plan												Future
	Month 12	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 1
Forecast sales (units)	210,000	253,000	280,000	340,000	300,000	391,600	220,000	285,000	420,000	280,000	128,000	527,000	393,000	267,000
Average daily forecast sales (units)	10,500	12,650	14,000	13,600	15,000	17,800	10,000	19,000	17,500	14,000	6,400	26,350	19,650	13,350
Actual sales (units)	200,000													
Operations plan (units)	220,000	306,400	306,400	383,000	306,400	337,040	337,040	229,800	367,680	306,400	306,400	306,400	306,400	
Average daily operations plan (units)	11,000	15,320	15,320	15,320	15,320	15,320	15,320	15,320	15,320	15,320	15,320	15,320	15,320	
Actual operations (units)	218,240													
Number of working days (days)	20	20	20	25	20	22	22	15	24	20	20	20	20	20
Number of workers required (persons)	1,364	1,915	1,915	1,915	1,915	1,915	1,915	1,915	1,915	1,915	1,915	1,915	1,915	
Ending inventory plan (units)	10,000	71,640	98,040	141,040	147,440	92,880	209,920	154,720	102,400	128,800	307,200	86,600	0	
Actual ending inventory (units)	18,240													
Days of supply (days)	1.44	5.12	7.21	9.40	8.28	9.29	11.05	8.84	7.31	20.13	11.66	4.41	0	
Fulltime hiring amount (persons)		551	-	-	-	-	-	-	-	-	-	-	-	
Fulltime layoff amount (persons)		-	-	-	-	-	-	-	-	-	-	-	-	

- In this example, an *average daily operations plan* is constant, and is achieved by dividing the net demand by the total working days in a year; i.e. $3,799,360/248=15,320$ units/day, or by multiplying the number of workers by the labor productivity; i.e. $1,915 \times 8=15,320$ units/day.

- *Ending inventory plan* amount is calculated by summing an operations plan in a month with an inventory plan amount in a previous month to achieve a total supply. This total supply amount is then deducted with the forecast sales amount in the same month to attain an inventory plan amount. For instance, an inventory plan amount in month 1 is $306,400+18,240-253,000=71,640$ units.

- *Day of supply* in month 1 is achieved by dividing an ending inventory plan amount of month 1 by an average daily forecast sales amount in month 2, which is $71,640/14,000=5.12$ days. To explain, an inventory amount of 71,640 units in month 1 is enough to supply the sales amount in month 2 for 5.12 days.

- *Fulltime hiring amount* in month 1 is $1,915-1,364=551$ persons. This hiring process only incurs in month 1, as the number of workers is kept constant afterwards based on the leveling strategy (i.e. 1,915 persons).

- There is no layoff throughout the planning period.

The number of workers in Example 2.2 is constant throughout the plan. This increases workers' loyalty, and improves work quality. Nevertheless, the inventory may be built-up when demand is less than the production output. In Example 2.2, a maximum inventory of 307,200 units is incurred in month 10 to supply the high demand in month 11. The inventory then becomes zero at the end of the planning period.

An estimate total cost of the S&OP in Example 2.2 can be calculated. It consists mainly on labor and inventory costs.

- Fixed cost of the 12-month period plan = $600 \times 12 = \$7,200$ (see Table 2.1).
- Variable cost is calculated based on the operations plans of the 12-month period i.e. $(306,400+306,400+383,000+306,400+337,040+337,040+229,800+367,680+306,400+306,400+306,400+306,400) \times 1.5 = \$5,699,040$.
- Labor cost is based on a number of fulltime workers in each month i.e. $1,915 \times 1,000 \times 12 = \$22,980,000$.

- Total inventory cost of the 12-month plan = $(71,640+98,040+141,040+147,440+92,880+209,920+154,720+102,400+128,800+307,200+86,600+0) \times 0.5 = \$770,340$.
- Fulltime hiring cost = $551 \times 200 = \$110,200$.
- Total cost of this plan = \$29,566,780.

The total cost of the 12-month plan following a leveling strategy is \$29,566,780. It is found that this strategy raises workers loyalty, yet the labor cost is high (almost 78% of the total cost). Apart from that, this strategy results in six times higher inventory cost than that in the chasing strategy (see Example 2.1), i.e. \$770,340 compared with \$109,440. So, might not be suitable when the inventory cost is high.

2.3.3 Mixed Strategy

Mixed strategy is commonly used in real practices, as it provides various options for the company. This strategy, however, requires high management commitment to get trade-offs between various functions prior to approving plan. A key decision is to decide what will be the decision variables at different time, such as stock keeping units, hiring amount, layoff amount, part time working, overtime working, under-time working, and subcontracting decisions.

Example 2.3 shows a mixed strategy by limiting the maximum hiring and layoff amount to be 200 and 100 persons/month, respectively. Part timer is only considered when the calculated fulltime workers are not an integer number, meaning that some full timers are not required to work full working hours/day. For instance, the required workers in month 2 are 1,742.50 persons. This is equivalent to 1,742 fulltime workers working 8 hours/day each, and a part timer working $0.5 \times 8 = 4$ hours/day. A maximum working hours/part timer/day is 4 hours in this strategy. If more production is needed, an overtime working may be considered with a maximum overtime units of 4 units/person/day. The company also needs to ensure a constant of 3 days of supply in each month. Extra stock is only allowed when layoff capacity is reached.

Example 2.3

An example of a mixed strategy

	History		Plan												Future	
	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month
	12	1	2	3	4	5	6	7	8	9	10	11	12	1		
Forecast sales (units)	210,000	253,000	280,000	340,000	300,000	391,600	220,000	285,000	420,000	280,000	128,000	527,000	393,000	267,000		
Average daily forecast sales (units)	10,500	12,650	14,000	13,600	15,000	17,800	10,000	19,000	17,500	14,000	6,400	26,350	19,650	13,350		
Actual sales (units)	200,000															
Operations plan (units)	220,000	250,240	278,800	344,200	307,360	368,200	350,592	227,040	359,368	283,474	267,474	299,474	331,474			
Average daily operations plan (units)	11,000	12,512	13,940	13,768	15,368	16,736.36	15,936	15,136	14,973.67	14,173.70	13,373.70	14,973.70	16,573.70			
Actual operations (units)	218,240															
Number of working days (days)	20	20	20	25	20	22	22	15	24	20	20	20	20	20		
Number of workers required (persons)	1,364	1,564	1,742.50	1,721	1,921	2,092	1,992	1,892	1,871	1,771	1,671	1,871	2,071			
Number of fulltime workers (persons)	1,364	1,564	1,742	1,721	1,921	2,092	1,992	1,892	1,871	1,771	1,671	1,871	2,071			
Part-time working hours (hours/day)	-	-	4	-	-	-	-	-	5.68	5.68	5.68	5.68	5.68			
Number of part timers (persons)	-	-	1	-	-	-	-	-	2	2	2	2	2			
Overtime plan (units)	-	26,520	-	-	1,040	-	-	-	-	-	-	-	101,528	42,626		
Overtime working hours (hours)	-	26,520	-	-	1,040	-	-	-	-	-	-	-	101,528	42,626		
Average daily overtime plan (units)	-	1,326	-	-	52	-	-	-	-	-	-	-	5,076.40	2,131.30		
Number of workers for overtime working (persons)	-	331.50	-	-	13	-	-	-	-	-	-	-	1,269.10	532.83		
Total operations plan (units)	220,000	276,760	278,800	344,200	308,400	368,200	350,592	227,040	359,368	283,474	267,474	401,002	374,100			
Ending inventory plan (units)	10,000	42,000	40,800	45,000	53,400	30,000	160,592	102,632	42,000	45,474	184,948	58,950	40,050			
Actual ending inventory (units)	18,240															
Days of supply (days)	1.44	3	3	3	3	3	8.45	5.86	3	7.11	7.02	3	3			
Fulltime hiring amount (persons)		200	178	-	200	171	-	-	-	-	-	200	200			
Fulltime layoff amount (persons)		-	-	21	-	-	100	100	21	100	100	-	-			

Calculation of each input is as the followings.

- Hiring case:
 - ▷ *Operations plan* is calculated based on the demand and the required inventory. To explain, the operations plan of month 1 is based on the demand in month 1 (i.e. 253,000 units) and the minimum required *ending inventory plan* of 3 days of supply in month 2 i.e. $14,000 \times 3 = 42,000$ units, totaling $253,000 + 42,000 = 295,000$ units. This demand is deducted with the on-hand inventory at the end of month 12 (history data) of 18,240 units, resulting in the operations plan of month 1 of $295,000 - 18,240 = 276,760$ units.
 - ▷ The *number of workers required* is then calculated based on the operations plan and the hiring condition. With the labor productivity of eight units/person/day and a 20-working day in month 1, a number of workers required in month 1 are $276,760 / (8 \times 20) = 1,729.75$ persons.
 - ▷ With the number of workers in month 12 (in the historical data) of 1,364 persons, this results in $1,729.75 - 1,364 = 365.75$ *fulltime hiring amount* in month 1.
 - ▷ The hiring amount is, however, limited at 200 persons/month, resulting in a total of $1,364 + 200 = 1,564$ fulltime workers working in month 1.
 - ▷ The operations plan must then be adjusted based on the real number of fulltime workers in month 1, which is $1,564 \times 8 \times 20 = 250,240$ units.
 - ▷ The leftover demand of $276,760 - 250,240 = 26,520$ units is fulfilled using the overtime working. However, it must not exceed the maximum overtime working units of 4 units/person/day. Compared with the maximum overtime working units in month 1 of $1,564 \times 4 \times 20 = 117,120$ units, the *overtime plan* of 26,520 units is set.
 - ▷ Total overtime working hour is calculated based on the labor productivity of 8 units/day or 1 unit/hour based on 8 normal working hours/day. *Overtime working hours* in month 1 are, therefore, $26,520 \times 1 = 26,520$ hours.

- Hiring and part timer case:
 - ▷ *Operations plan* of month 2 is based on the demand in month 2 (i.e. 280,000 units) and the minimum required *ending inventory plan* of 3 days of supply in month 3 i.e. $13,600 \times 3 = 40,800$ units, totaling $280,000 + 40,800 = 320,800$ units. This demand is deducted with the ending inventory of month 1 of 42,000 units, resulting in the operations plan of month 2 of $320,800 - 42,000 = 278,800$ units.
 - ▷ The *number of workers required* is then calculated based on the operations plan and the hiring condition. With the labor productivity of eight units/person/day and a 20-working day in month 2, a number of workers required in month 2 are $278,800 / (8 \times 20) = 1,742.50$ persons.
 - ▷ With the number of workers in month 1 of 1,564 persons, this results in $1,742.50 - 1,564 = 178.50$ *fulltime hiring amount* in month 2.
 - ▷ With only full timers are considered, 178.50 fulltime hiring amount becomes 178 fulltime hiring amount and 1 part timer working $0.5 \times 8 = 4$ hours/day in month 2.
- Layoff case:
 - ▷ *Operations plan* of month 6 is based on the demand in month 6 (i.e. 220,000 units) and the minimum required inventory of 3 days of supply in month 7 i.e. $19,000 \times 3 = 57,000$ units, which totals $220,000 + 57,000 = 277,000$ units. This demand is deducted with the ending inventory of month 5 of 30,000 units, resulting in the operations plan of month 6 of $277,000 - 30,000 = 247,000$ units.
 - ▷ The *number of workers required* is then calculated based on the operations plan and the layoff condition. With the labor productivity of eight units/day and a 22-working day in month 6, a number of workers required in month 6 are $247,000 / (8 \times 22) = 1,403.41$ persons.
 - ▷ With the number of workers in month 5 of 2,092 persons, this results in $2,092 - 1,403.41 = 688.59$ *fulltime layoff amount* in month 6.
 - ▷ The layoff amount is, however, limited at 100 persons/month, resulting in a total of $2,092 - 100 = 1,992$ fulltime workers working in month 6.

- ▷ The operations plan must then be adjusted based on the real number of fulltime workers in month 6, which is $1,992 \times 8 \times 22 = 350,592$ units.
 - ▷ This adjusted operations plan (i.e. 350,592 units) is added with the on-hand inventory in month 5 (i.e. 30,000 units) to achieve a total supply in month 6, which is $350,592 + 30,000 = 380,592$ units.
 - ▷ With the demand in month 6 of 220,000 units, an oversupply of $380,592 - 220,000 = 160,592$ units is kept as the *ending inventory plan* amount in month 6. This is equivalent to $160,592 / 19,000 = 8.45$ days of supply in month 7.
- Layoff and part timer case:
 - ▷ *Operations plan* of month 8 is based on the demand in month 8 (i.e. 420,000 units) and the minimum required inventory of 3 days of supply in month 9 i.e. $14,000 \times 3 = 42,000$ units, which totals $420,000 + 42,000 = 462,000$ units. This demand is deducted with the ending inventory of month 7 of 102,632 units, resulting in the operations plan of month 8 of $462,000 - 102,632 = 359,368$ units.
 - ▷ The *number of workers required* is then calculated based on the operations plan and the layoff condition. With the labor productivity of eight units/day and a 24-working day in month 8, a number of workers required in month 8 are $359,368 / (8 \times 24) = 1,871.71$ persons.
 - ▷ With the number of workers in month 7 of 1,892 persons, this results in $1,892 - 1,871.71 = 20.29$ fulltime layoff amount in month 8.
 - ▷ As only fulltime layoff amount is considered, this results in 21 fulltime layoff amount, and leads to $1,892 - 21 = 1,871$ fulltime workers working in month 8.
 - ▷ With the required workers of 1,871.71 persons and the full timers of 1,871 persons in month 8, part timers are needed to fulfill $1,871.71 - 1,871 = 0.71$ person. This is equivalent to $0.71 \times 8 = 5.68$ part time working hours/day.
 - ▷ However, a maximum working hours/part timer/day is 4 hours in this strategy. This leads to 2 part timers required in month 8.

In Example 2.3, more workers are hired and overtime working is used to support an increased demand at the first half of the year. In the second half of the year, however, the demand decreases, leading to layoff and stock keeping. The highest ending inventory of 184,948 units is expected to be kept at the end of month 10. This could lead to high inventory cost at the end of the planning period.

An estimate total cost of the S&OP in Example 2.3 can be calculated (see cost data in Table 2.1). It consists of fixed, variable, labor, part time working, overtime working, inventory, hiring, and layoff costs.

- Fixed cost of the 12-month period plan = $600 \times 12 = \$7,200$.
- Variable cost is calculated based on the operations plans of the 12-month period i.e. $(276,760 + 278,800 + 344,200 + 308,400 + 368,200 + 350,592 + 227,040 + 359,368 + 283,474 + 267,474 + 401,002 + 374,100) \times 1.5 = \$5,759,115$.
- Labor cost is based on a number of fulltime workers in each month i.e. $(1,564 + 1,742 + 1,721 + 1,921 + 2,092 + 1,992 + 1,892 + 1,871 + 1,771 + 1,671 + 1,871 + 2,071) \times 1000 = \$22,179,000$.
- Part timer cost = $\{(4 \times 20) + [5.7 \times (24 + 20 + 20 + 20 + 20)]\} \times 3.5 = \$2,354.80$.
- Overtime cost is calculated based on a number of overtime working hours i.e. $(26,520 + 1,040 + 101,528 + 42,626) \times 7 = \$1,201,998$.
- Total inventory cost for the 12-month plan = $(42,000 + 40,800 + 45,000 + 53,400 + 30,000 + 160,592 + 102,632 + 42,000 + 45,474 + 184,948 + 58,950 + 40,050) \times 0.5 = \$422,923$.
- Fulltime hiring cost = $(200 + 178 + 200 + 171 + 200 + 200) \times 200 = \$229,800$.
- Fulltime layoff cost = $(21 + 100 + 100 + 20 + 100 + 100) \times 500 = \$220,500$.
- Total cost of this plan = $\$30,022,890.80$.

The total cost of the 12-month plan following a mixed strategy is $\$30,022,890.80$. Major costs come from labor, variable, and overtime costs respectively. Maximum overtime working hour is in month 11 (i.e. 101,528 hours). This may lead to fatigue and low productivity. To reduce the overtime cost, the company may consider using more part timers, or allow more part time working hours/day. However, the quality of work might be an issue to concern, as part timers might not have as high skills as fulltime workers.

2.4 Issues Concerned with the S&OP

Implementing an S&OP requires cooperation from all the functions in the company. Top management must commit to the S&OP processes by establishing the S&OP teamwork, modifying any performance measures to align with the plan, resolving the conflicts, and forcing the resolution of trade-offs between the functions prior to approving the plan. For example, if the production department continues to produce while the customer order reduces, then the inventories increase causing increased total cost. On the other hand, if no supported solution is provided for increased or fluctuated demand, stock out occurs, leading to less profit for the company.

All functions in the company must also cooperate to achieve the S&OP goals. They need to communicate when problems happen, as soon as the problems are solved, the better the company's performance. It is also necessary to have a cross-functional team with the appropriate skill to execute the S&OP. For example, the marketing department should sell what is in the S&OP; overselling or underselling should not happen as it affects the company's performance. On the other hand, if an opportunity arises to sell more than what is stated in the plan, the marketing department should communicate with the related functions to adjust the S&OP. Similarly, as a production department, overproduction may incur high inventory cost, while underproduction may create a stock out; both mean poor performance. When the production matches the S&OP, the finance department can effectively plan for cash flows, and the marketing department can provide good customer order promises and services.

Conclusion

The S&OP is an important step of any manufacturing process. A well-designed and executed plan leads to a high company's performance. A summary of this chapter is as follows:

- The S&OP is a statement of desired production output, not a forecast.
- It requires a good cooperation and communication between the functions in the company.
- Trade-offs required to set the S&OP must be made prior to final approval.

- Different S&OPs may be possible; however, the implemented plan must be directly related to the company's strategic plan.
- Three possible strategies are illustrated in this chapter, including the chasing, leveling, and mixed strategies.
- While the chasing strategy is simple and easy to implement, it causes high total cost.
- Leveling strategy is recommended for high-skilled production, as workers are kept throughout the planning period, thus raising skills and experiences.
- Mixed strategy is mostly applied in the real practices, as it considers various options to be implemented. It could also be adjusted to suit with any changes.
- Top management commitment is significant in an S&OP development.
- An S&OP performance assessment is needed to attain an effective S&OP.

Apart from the strategies and techniques used in this chapter, other techniques may be applied in the real practices, such as the uses of subcontractors, backorders, and backlogs. The S&OP might not be suitable for modular or make-to-order manufacturing, as quantity is not an issue.

An accurate S&OP can provide accurate master production schedule and material requirement plan, as detailed in the next chapters.

Case Studies

TGC Co., Ltd. Sales and Operations Planning (Hattakee, 2011)



TGC Co., Ltd. is a food manufacturing company mainly produces snack under “Glico” brand. The two factories, located in Rangsit and Pathumthani, Thailand, are mainly used to produce nine products. Currently, the company develops different strategies for different products. S&OP is not used to integrate all production requirements into a single strategy. This results in stock out and lost sales. The company then attempts to improve the production efficiency by using a number of strategies, such as the ABC analysis, exponential smoothing forecasting technique, and S&OP. The 3-month historical data are used to examine production, sales, and inventory amount. The 3-month sales forecast were, on the other hand, used to plan for the production.

Prior to developing the S&OP for all products, the S&OP team summarizes key issues for consideration, including approval of the sales forecast from the marketing department, examination of the demand and supply balancing plan, prioritization of the sales orders, and determination of inventory target. The S&OP is then developed, and the stock out cost and lost sales are examined and compared with the historical data (see below table). It is found that by developing the S&OP, the company reduces the lost sales by almost 90% (from 74.46 million Baht to 7.67 million Baht).

Code	Demand (x100 units)	Unit cost (Baht)	Stock out (Units)		Reduction in stock out (%)
			Individual plan for each product	S&OP plan for all nine products	
CX15	17,584	1,306.57	8,086	176	97.82
AL06	80,852	522	26,538	6,214	76.59
CS06	25,395	522.89	3,934	152	96.14
TW10	43,593	870	8,086	1,615	80.03
AM25	80,660	1,067	12,234	1,960	83.93
CC15	60,492	1,306	6,276	294	95.31
CA06	40,073	523	3,951	374	90.54
PO15	214,294	1,305	11,377	0	100.00
PS15	133,760	1,305	1,949	0	100.00

Code	Demand (x100 units)	Unit cost (Baht)	Lost sales (Baht)		Reduction in lost sales (%)
			Individual plan for each product	S&OP plan for all nine products	
CX15	17,584	1,306.57	10,564,964.22	230,217.63	97.82
AL06	80,852	522	13,853,190.96	3,243,509.64	76.59
CS06	25,395	522.89	2,056,965.60	79,369.47	96.14
TW10	43,593	870	7,034,880.90	1,405,076.10	80.03
AM25	80,660	1,067	13,298,466.70	2,137,422.45	83.93
CC15	60,492	1,306	8,196,678.02	384,577.82	95.31
CA06	40,073	523	2,066,132.42	195,434.64	90.54
PO15	214,294	1,305	14,846,763.15	0	100.00
PS15	133,760	1,305	2,543,771.25	0	100.00
Total			74,461,813.22	7,675,607.75	89.69

- a) Please explain why the S&OP helps reduce the stock out and lost sales in the company?
- b) Which products should the company focus to further reduce lost sales and increase the profit?

Exercises

- 2.1 Develop an S&OP for Jade Buildup Company using a chasing strategy in *Example 2.1*, and the cost data as shown in Table 2.1. In this plan, however, the company intends to keep no inventory throughout the 12-month plan (see Exercise 2.1 table below).
- a) What is the total cost of this plan?
 - b) Is days of supply zero in this plan?
 - c) Does the company need part timers? If yes, how many part timers will be needed throughout the plan?
- 2.2 Based on Exercise 2.1, if Jade needs to use the chasing strategy, together with a constant of 5 days of supply in each month, please update the plan (see Exercise 2.2 table below).
- a) What is the total cost of this plan?
 - b) What is the maximum amount of inventory and in what month?
- 2.3 Jade, the owner of the company, considers the leveling strategy in *Example 2.2* and the cost data in Table 2.1, and wants to make an adjustment. He needs to keep 18,240 units of inventory at the end of the plan. Please help Jade revise the plan (see Exercise 2.3 table below).
- a) What is the total cost of this plan?
 - b) Which month has the highest days of supply?
 - c) Which month has the highest amount of ending inventory?
 - d) Is the answer of questions b) and c) the same? Please explain.
 - e) How many fulltime workers are hired at the beginning of this plan?

Exercise 2.2

[illegible]

- 2.4 Based on *Example 2.2*, if Jade wants to keep a constant number of workers of 1,364 (i.e. leveling strategy with no hiring and layoff), and utilizes the subcontracting option to fulfill the demand (see Exercise 2.4 table below).
- a) What is the total cost of this plan?
 - b) How many units does the company outsource in total?
 - c) In which month does the company have a maximum outsource units?
 - d) In which month does the company have maximum days of supply?
- 2.5 Jade considers a mixed strategy for his new production plan. He considers *Example 2.3*, and wants to change two conditions: 1) keeping 3 days of supply or 30,000 units of inventory, whichever is smaller, 2) hiring is still limited at 200 persons/month, whereas layoff amount is unlimited. (see Exercise 2.5 table below)
- a) What is the total cost of this plan?
 - b) How many months do the company keep 30,000 units of inventory?
 - c) How many months do the company keep 3 days of supply?
- 2.6 Based on Exercise 2.5, Jade also wants to ensure that his original workers will not be sacked, meaning that the minimum number of workers each month must be 1,364 persons. He then allows a maximum inventory of 50,000 units to be kept each month. Keeping more than the maximum inventory amount is possible, if necessary; however, the inventory cost/unit/month of over 50,000 units will be double (see Exercise 2.6 table below).
- a) What is the total cost of this plan?
 - b) How many months do the company keep more than 50,000 units of inventory?

Exercise 2.5

	History		Plan												Future	
	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month
	12	1	2	3	4	5	6	7	8	9	10	11	12			1
Forecast sales (units)	210,000	253,000	280,000	340,000	300,000	391,600	220,000	285,000	420,000	280,000	128,000	527,000	393,000			267,000
Average daily forecast sales (units)	10,500															
Actual sales (units)	200,000															
Operations plan (units)	220,000															
Average daily operations plan (units)	11,000															
Actual operations (units)	218,240															
Number of working days (days)	20	20	20	25	20	22	22	15	24	20	20	20	20			20
Number of workers required (persons)	1,364															
Number of fulltime workers (persons)	1,364															
Part-time working hours (hours/day)	-															
Number of part timers (persons)	-															
Overtime plan (units)	-															
Overtime working hours (hours)	-															
Average daily overtime plan (units)	-															

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This text book is a good source for readers who are interested in learning basic knowledge of production and inventory management. Enjoy the book!!!

Thanwadee Chinda

Associate Professor

Sirindhorn International Institute of Technology,

Thammasat University

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