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Production and Material Planning in the Push and Pull Integrated System for Routine Products and Customers' Orders

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Abstract

In this article the push and pull production system is investigated and the proper policies are presented to facilitate the production of customers' orders and routine products. In this push and pull integrated manufacturing system we should choose the best production methods in different circumstances. Using linear programming is the method used to calculate the MPS and based on that MRP and SFC (for 4 weeks) are determined. Besides, the customers' orders and all the material needed are added to the plan. The production system and raw material preparation are different in push and pull systems and the best decision should be made to consume the investment efficiency and deliver the production as customers need. In addition, a cycle of receiving orders from sales department is suggested. The results of calculation the plans for MPS, MRP, SFC, customers' orders, etc. are determined. After calculating the MPS based on the push system, the orders are investigated for SFC and MRP system. Solving these models isn't easy and soluble unless useful and comprehensive methods are used. This is a job sequences production line which is push and pull integrated system.

Keywords: Assemble-to-order, Linear Programming, Matrix-BOM, MPS, SFC

1. Introduction

Production-oriented companies try to increase their productivity and reduce their costs so accurate plans can play a vital role for this purpose. As the matter of fact, in production systems, the timetable of workstations and their materials planning should be prepared by schedulers. In this article a production model with five workstations is clarified but the method of planning for each stage is different and they have a different SFC in proportion to the individual orders. The planning of the first and second stage is determined by push system but other workstations plans are organized based on the both push and pull systems. Albeit, the main purpose of this article is related to how we can integrated these types of plans with each other in SFC and MRP sheets. This model is an assemble-to-order model because the production systems has a wide-spread relationship with orders and pull system. Furthermore, this is a job sequences model with different batch sizes. The flowchart below (Figure 1) shows the main six steps with a little description.

As the chart vividly illustrates, at first, MPS of this model is calculated based on the linear programming method. The number of production that are needed for each month are depend on different factors such as sales forecasting, primary inventory, safety stock, the cost of the products, etc. At the second step, the number of materials that are needed is calculated in order to complete the process. At the final step of push production system, SFC is calculated for each week. Next, the customers' orders should be considered (another plan based on pull system). So SFC and Material planning are changed. But this system should be well-organized and increased the flexibility of production line. Finally, all of these plans in both systems should be integrated in the SFC sheets and the output of Matrix-BOM. In addition, sufficient safety stock should be stored in the production line.

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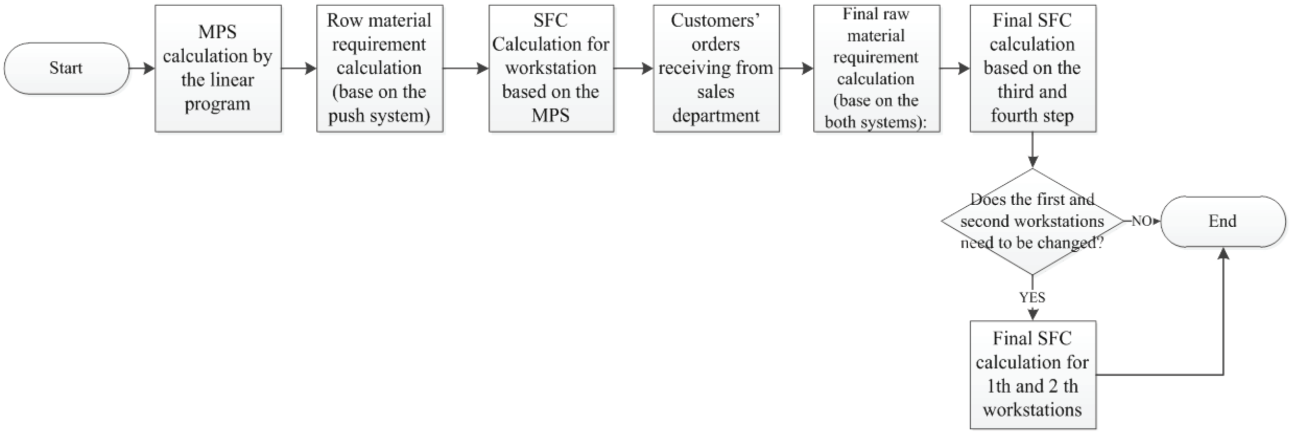


Figure 1. Six main steps of solving a push and pull integrated method.

2. Literature Review

2.1 MPS Method

MPS is a plan to produce for production, staff, inventory, etc. This is related to the time and quantity. One of the purposes of MPS is optimizing the production lines. Besides, forecasting the future plans is another part of MPS (en.wikipedia.org/). Production-oriented companies have a lot of problems in combination with constantly changing process parameters that an accurate and correct plan can solve this[1]. There are a lot of factors that have effect on manufacturing system performance such as orders, limited resources, quality deterioration, machines, etc[2]. All of these factors are considered in MPS[3] Planning and control provides the systems, sequences and policies which have different approach of both supply and demand[4]. There are a lot of model for production process management with external and internal risks such as demands, yield, capacity, etc. and they should be studied by operation researcher's[5]. Planning and Control is related to market needs and operation's resources ability or capacity[4] and production planning and inventory control have been solved by production researchers and Simone was the first researcher who analyzes simple production-inventory systems[6]. In Spite of the fact that automation of production is very important, control systems should have the process information in real-time[1].

Production planning structure is organized as the Table 1 shows:

The Figure 2 illustrates the MRP close-loop for a push production system[7]:

Table 1. Production planning structure

Resources	Capacity Planning	Production Planning	Planning
Manufacture	Resource Requirement Planning	Aggregate Planning	Production
Critical Work Center	Rough out Capacity Planning	Master Production Schedule	Final Product
Work Center	Capacity Requirement Planning	Material Requirement Planning	Part
Machines and Equipment	Input-Output Control	Shop Floor Scheduling	Production Operation

2.2 Assemble-To-Order

An Assemble-To-Order (or ATO) system contains different kinds of components. To make the products some of these components are needed and the products are assembled in respond to demand (Song). In this method, there is a lot of variety of products. In final process of production, the products might be changed in proportion to orders and it leads to decrease the number of products in warehouse because when they are produced, they will delivery to the customers that ordered the production. Thus, it decreases the WIP and warehouse inventory[7] and in this system production should concentrate on high volume[8]. The Figure 3 compares make-to-stock, assemble-to-stock and make-to-order with each other:

2.3 Material Planning and Inventory Control

Inventory costs contain different factors such as holding, ordering, shortage; setup costs[9]. There two types of multi

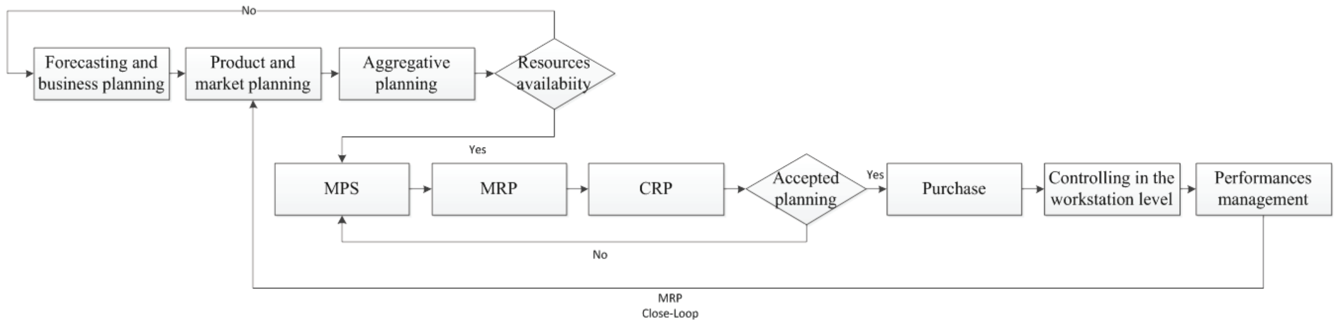


Figure 2. MRP close-loop.

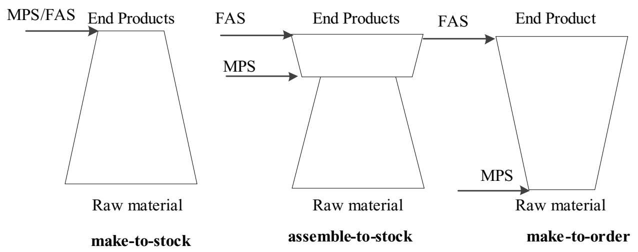


Figure 3. Make-to-stock, assemble-to-stock and make-to-order systems.

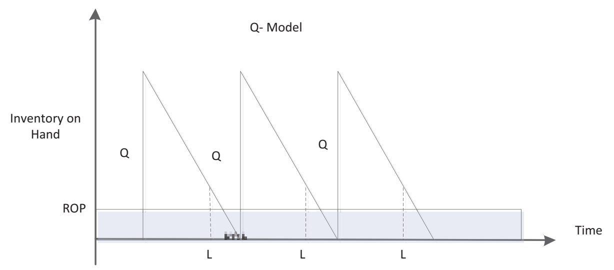


Figure 4. Basic fixed-order quantity model.

period inventory system: fixed-order quantity model and fixed-time quantity model. In the first one, total annual cost is calculated:

Total cost annual cost = Annual purchase cost + Annual ordering cost + Annual holding cost

$$TC = DC + S.\frac{D}{Q} + H.\frac{Q}{2}$$

TC = Total cost
H = Holding cost
Q = Quantity
D = Demand
C = Cost per unit
S = Setup cost

$$\xrightarrow[]{\textit{Derive the TC}} Q^* = \sqrt{\frac{2DS}{H}}$$

$$ROP = LT.\bar{d}$$

$\bar{d}$ = Average daily demand

LT = Lead Time

The formula below shows the calculation of fixed-order quantity model with safety stock:

$$ROP = LT.\bar{d} + SS$$

In the fixed-time period model, that inventory is calculated only at particular times, the order quantity is calculated as the formula below shows:

Order quantity = Average demand over the vulnerable period + Safety stock - Inventory Current on hand

$$q = (LT + T).\bar{d} + SS - I$$

T = the number of days between reviewers[9]

3. Proposed Methodology and Results

The production line contains 5 workstations. In spite of the fact that the first and second one are planned base on the push production system, sometimes customers' orders have effect on these workstations. The Figure 5 clarifies the method of planning in this model:

This production line is an electronic controlling system and it produces 4 different sorts of product (x1, x2, x3, and x4). All the stages in this model are calculated in basis of pull and push integrated method. The products of customers' orders are x1, x2, x3, and x4 with a little

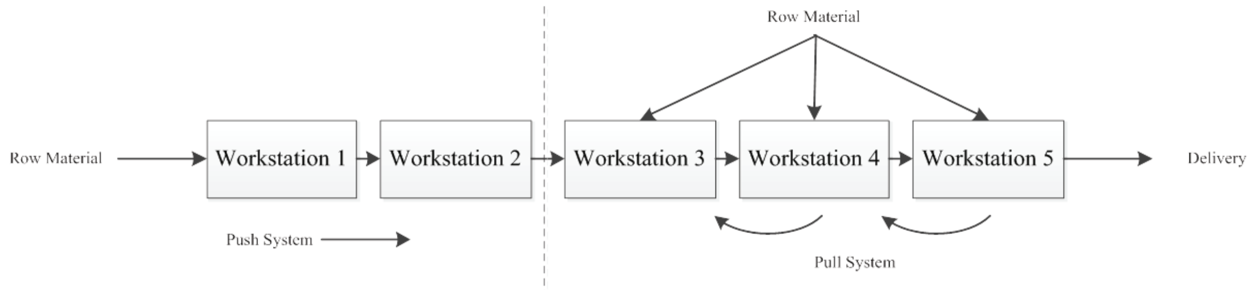


Figure 5. Push and pull integrated model.

change with different materials. In fact, for each order, just one or two materials might be changed.

3.1 MPS Calculation by the Linear Programing

The MPS of this model relates with the batch of orders, benefit of each product, project on hand, Available To Promise (ATP), the number of drives ordered, capacity of production line, the maximum number of sales requirement, etc. There are different kinds of hypothesis to calculate MPS such as:

a. Drives are consumed only in x1 products (consumption factor = 1).
b. The Table 2 shows data on the net-profit of each product:
c. The capacity of production line is 450 products per month.
d. The MPS is calculated for one month and SFC is based on this plan but it considers the plan for one week.

So, the linear programing is modeled and then is solved with software:

Max Z = 30000.x1 + 5000.x2 + 4000.x3 + 1000.x4

S.t: x1<= the number of drives ordered +Inventory of drives

The number of customers' orders x1 <= x1

The number of customers' orders x2 >= x2

The number of customers' orders x3 >= x3

Table 2. Net-profit of each product

Products	Drive	net-profit
X1	YES	C1 = 30000
X2	NO	C2 = 5000
X3	NO	C3 = 4000
X4	NO	C4 = 1000

The number of customers' orders x4 >= x4

X1 + X2 + X3 <= Capacity of production line = 450 products for each month

As the results show, solution value is the number of products that should be produced. Furthermore, the benefit of each product is calculated in Unit or Profit c (j). Besides, the below formula shows Total Contribution:

Total Contribution = c (j) * (x1 + x2 + x3 + x4)

Albeit, there are different sorts of method to calculate ATP such as: discrete, without look ahead and with look ahead.

3.2 Raw Material Requirement Calculation (based on the Push System)

The results of MRP are the output of MPS and besides MPS, it needs several items such as Lead Time (LT), Minimum of Quantity (MOQ), Batch Size (BS), Q*, the average of goods consumption, etc. The output of MRP is Reorder Point (ROP). In this stage, at first, the Matrix-BOM should be prepared based on the BOM of each 5 products. The diagram below shows the part name, their quantity and codes, etc. Then in the Matrix-BOM, all of the BOM for 4 products are integrated as in the Figure 6 is determined.

There are different sorts of data needed to solve this problem. The Table 4 shows the final Matrix-BOM:

At this time, the number of material that should be prepared for products is calculated.

The number of materials we need is calculated and the results are in the Table 5, although in the sixth stage the materials planning will be changed because of the customers' orders:

3.3 SFC for Workstation based on the MPS

When MPS was determined, each workstation needed to have a clear and precise plan in order to produce

Table 3. Results of MPS and details of that

	15:48:52		Friday	May	16	2014		
	Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
1	X1	250/0000	30،000/0000	7،500،000/0000	0	basic	4،000/0000	M
2	X2	124/0000	5،000/0000	620،000/0000	0	basic	4،000/0000	M
3	X3	76/0000	4،000/0000	304،000/0000	0	basic	0	5،000/0000
4	X4	18/0000	1،000/0000	18،000/0000	0	basic	0	M
	Objective	Function	(Max.) =	8،442،000/0000				
	Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
1	C1	250/0000	<=	250/0000	0	26،000/0000	227/0000	326/0000
2	C2	250/0000	>=	226/0000	24/0000	0	-M	250/0000
3	C3	124/0000	<=	124/0000	0	1،000/0000	101/0000	200/0000
4	C4	76/0000	<=	99/0000	23/0000	0	76/0000	M
5	C5	18/0000	<=	18/0000	0	1،000/0000	0	M
6	C6	450/0000	<=	450/0000	0	4،000/0000	374/0000	473/0000

		X1	X2	X3	X4	Slack_C1	Surplus_C2	Slack_C3	Slack_C4	Slack_C5	Slack_C6	Artificial_C2		
Basis	C(j)	30،000/0000	5،000/0000	4،000/0000	1،000/0000	0	0	0	0	0	0	0	R. H. S.	Ratio
Slack_C1	0	1/0000	0	0	0	1/0000	0	0	0	0	0	0	250/0000	250/0000
Artificial_C2	-M	1/0000	0	0	0	0	-1/0000	0	0	0	0	1/0000	226/0000	226/0000
Slack_C3	0	0	1/0000	0	0	0	0	1/0000	0	0	0	0	124/0000	M
Slack_C4	0	0	0	1/0000	0	0	0	0	1/0000	0	0	0	99/0000	M
Slack_C5	0	0	0	0	1/0000	0	0	0	0	1/0000	0	0	18/0000	M
Slack_C6	0	1/0000	1/0000	1/0000	0	0	0	0	0	0	1/0000	0	450/0000	450/0000
	C(j)-Z(j)	30،000/0000	5،000/0000	4،000/0000	1،000/0000	0	0	0	0	0	0	0	0	
	* Big M	1/0000	0	0	0	0	-1/0000	0	0	0	0	0	0	

asem_no	sta_no	sta_nam	com_qty	preplace
11040770	061398	Board 1	1	
11040771	061398	Board 2	1	
11040772	061398	Board 3	1	
11040773	061398	Board 4	1	
11040774	061398	Board 5	1	
11040775	061398	Drive	1	R1
11040776	061398	Contactor1	2	R2
11040777	061398	Contactor2	1	R3
11040778	061398	Box	1	
11040779	061398	Screen	1	
11040780	061398	Wire	1	

asem_no	sta_no	sta_nam	com_qty	preplace
11040770	061398	Board 1	1	
11040771	061398	Board 2	1	
11040772	061398	Board 3	1	
11040773	061398	Board 4	0	
11040774	061398	Board 5	0	
11040775	061398	Drive	0	R1
11040776	061398	Contactor1	1	R2
11040777	061398	Contactor2	0	R3
11040778	061398	Box	1	
11040779	061398	Screen	1	
11040780	061398	Wire	1	

asem_no	sta_no	sta_nam	A	B	C	D
11040770	061398	Board 1	1	1	1	1
11040771	061398	Board 2	1	1	1	1
11040772	061398	Board 3	1	1	0	0
11040773	061398	Board 4	1	0	0	0
11040774	061398	Board 5	1	0	0	1
11040775	061398	Drive	1	0	0	0
11040776	061398	Contactor1	2	1	1	1
11040777	061398	Contactor2	1	0	1	0
11040778	061398	Box	1	1	1	1
11040779	061398	Screen	1	1	1	1
11040780	061398	Wire	1	1	1	1

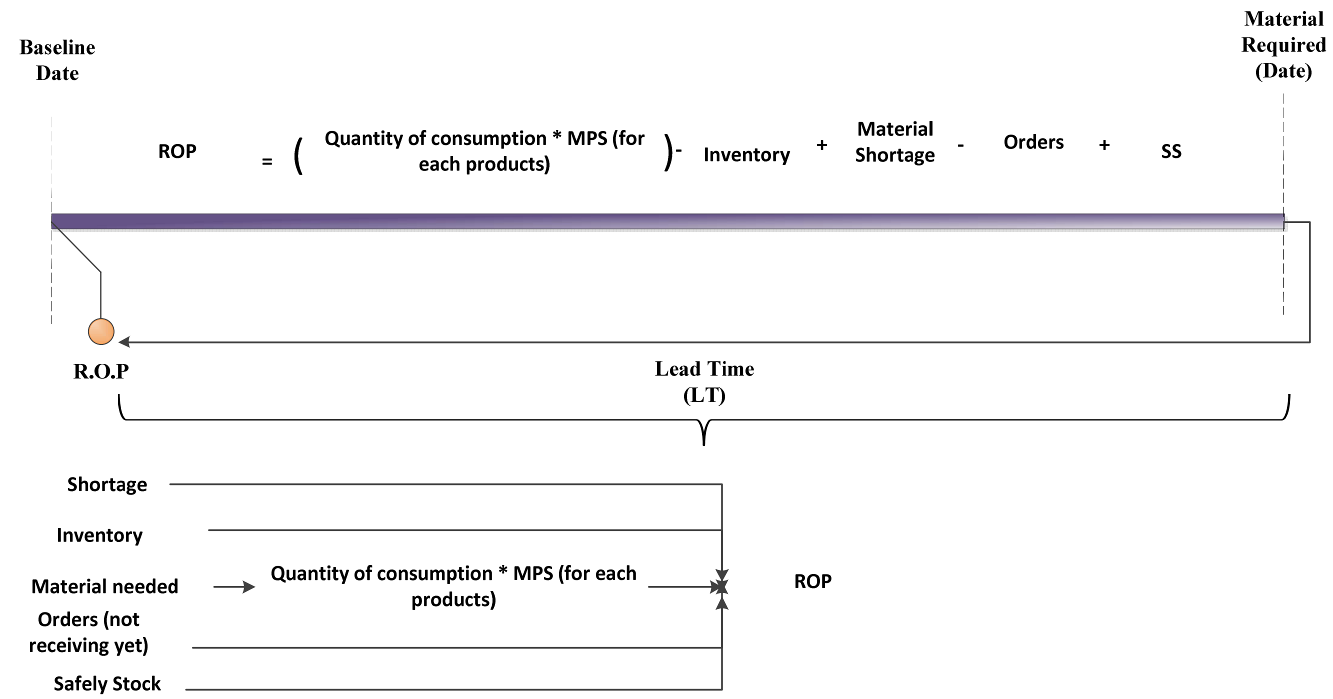
asem_no	sta_no	sta_nam	com_qty	preplace
11040770	061398	Board 1	1	
11040771	061398	Board 2	1	
11040772	061398	Board 3	0	
11040773	061398	Board 4	0	
11040774	061398	Board 5	0	
11040775	061398	Drive	0	R1
11040776	061398	Contactor1	1	R2
11040777	061398	Contactor2	1	R3
11040778	061398	Box	1	
11040779	061398	Screen	1	
11040780	061398	Wire	1	

asem_no	sta_no	sta_nam	com_qty	preplace
11040770	061398	Board 1	1	
11040771	061398	Board 2	1	
11040772	061398	Board 3	0	
11040773	061398	Board 4	0	
11040774	061398	Board 5	1	
11040775	061398	Drive	0	R1
11040776	061398	Contactor1	1	R2
11040777	061398	Contactor2	0	
11040778	061398	Box	1	
11040779	061398	Screen	1	
11040780	061398	Wire	1	

Figure 6. The BOM of each product and Matrix-BOM.

Table 4. Matrix-BOM and essential data

asem_no	sta_name	A	B	C	D	lead time(week)	MOQ	batch Quantity	SS	average usage	ROP
		X1	X2	X3	X4						
11040770	Board 1	1	1	1	1	3	10	1	2	5	17
11040771	Board 2	1	1	1	1	3	10	1	2	11/25	36
11040772	Board 3	1	1	0	0	3	10	1	2	0	2
11040773	Board 4	1	0	0	0	3	10	1	2	0	2
11040774	Board 5	1	0	0	1	1	100	2	30	40	70
11040775	Drive	1	0	0	0	4	50	1	10	12/5	60
11040776	Contactor1	2	1	1	1	4	50	1	10	1/25	15
11040777	Contactor2	1	0	1	0	4	50	1	10	11/25	55
11040778	Box	1	1	1	1	4	50	1	10	5	30
11040779	Screen	1	1	1	1	4	50	1	10	7/5	40
11040780	Wire	1	1	1	1	4	50	1	10	25	110



the process of production in proportion to that. Thus, MPS plan should be divided to four distinguish plans for each week and they are clarified by the wardens to the workers. These plans are calculated based on the orders that sales department needed for customers. Thus, the MPS shows the plan of each product for the first workstations.

3.4 Customers' Orders Receiving from Sales Department

Besides the routine orders, sales department need some specific products that their materials and structures are different from the routine one. So, production planner should consider these plans and prepare all the

Table 5. The number of materials for purchasing

asem_no	sta_name	A	B	C	D	lead time	MOQ	SS	average usage	ROP	Date	Inventory
		X1	X2	X3	X4							
		250	124	76	18							
11040770	Board 1	1	1	1	1	3	10	2	5	257	776	213
11040771	Board 2	1	1	1	1	3	10	2	11/25	395	1196	0
11040772	Board 3	1	1	0	0	3	10	2	0	376	1128	0
11040773	Board 4	1	0	0	0	3	10	2	0	218	654	34
11040774	Board 5	1	0	0	1	1	100	30	40	296	336	2
11040775	Drive	1	0	0	0	4	50	10	12/5	249	1009	11
11040776	Contactor1	2	1	1	1	4	50	10	1/25	638	2553	14
11040777	Contactor2	1	0	1	0	4	50	10	11/25	215	871	46
11040778	Box	1	1	1	1	4	50	10	5	367	1473	36
11040779	Screen	1	1	1	1	4	50	10	7/5	368	1480	35
11040780	Wire	1	1	1	1	4	50	10	25	401	1629	2

Table 6. SFC for each week based on MPS

product name	Inventory		week 1	week 2	week 3	week 4	total
A	30	forecast	20	110	200	50	380
		Backlog	10	10	5	15	40
		total demand	30	120	205	65	420
		POH	0	0	−85	−130	−215
		MPS		120	120	20	260
		ATP: D	−30	110	75	−35	120
B	30	forecast	10	60	10	30	110
		Backlog	40	0	30	30	100
		total demand	50	60	40	60	210
		POH	−10	−10	−20	−50	−90
		MPS	10	60	30	30	130
		ATP: D	−100	60	−100	−100	−240
C	0	forecast	20	25	10	15	70
		Backlog	5	5	0	0	10
		total demand	25	30	10	15	80
		POH	−15	−15	5	−4	−29
		MPS	10	30	30	6	76
		ATP: D	−10	25	20	−4	31
D	10	forecast	0	5	0	4	9
		Backlog	0	10	5	0	15
		total demand	0	15	5	4	24
		POH	10	0	−5	−4	1
		MPS		5		5	10
		ATP: D	−15	−20		−10	−45

materials as well as routine one. These products should be delivered to customers without any delay even its justifiable. E-KANBAN is a popular method to transfer this information for another department such as planning and production management as soon as possible. In addition, these orders shouldn't have any mistake because it misleads production department and they spend a lot of resources for unnecessary products. So, accuracy and quickness to transfer this information play a vital role for production. After receiving this information by production and manufacturing department they should prepare all the materials and produce the orders in proportion to customers' needs. This stage is very important and has a lot of influence on customers' satisfaction. Thus, a vivid duty for the entire department should be prepared in order to accelerate all of these workflows. The flowchart below (Figure 7) illustrates a suggestion workflow to transfer customers' orders until delivery the products.

In this model, this sheet contains the power and name of drive, the method of connection to engine and the stops of system, etc. So, in proportion to this information, drive, board and contactor will be changed. Now, a specific sheet which is received from sales department is investigated. It leads some changes that Table 7 shows them certainly:

3.5 Final Raw Material Requirement Calculation (base on the Both Systems)

As in the previous stage, all the materials that we need for customers' orders are calculated based on the production quantity, now the raw materials preparation should be

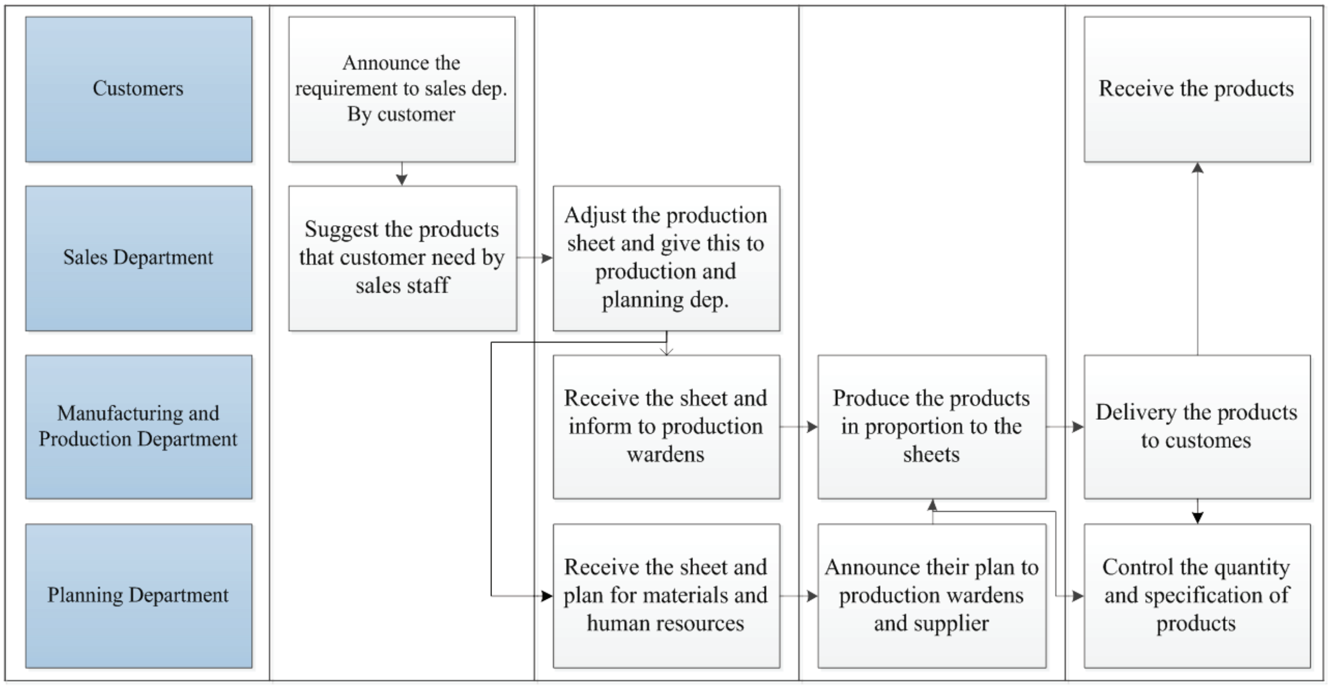


Figure 7. Cycle of receiving the orders from sales department.

Table 7. Rudiment needs for orders

asem_name	Rudiment Needs
Board 1	1
Board 2	0
Board 3	0
Board 4	0
Board 5	0
Drive	0
Contactor1	0
Contactor2	0
Box	0
Screen	0
Wire	0
Board X	4
Board Y	3
Drive X	5

calculated and announced to supplier or other related departments. In this method, we consider both stages 3.2 and 3.4 results and the formula below suggests solving this types of integrated model:

ROP = (Quantity of consumption * MPS) - Inventory + Material Storage - Orders + Safety Stock + rudiment needs

The Table 8 clarifies information on the final ROP that should be ordered at this time (after receiving the sales orders).

3.6 Final SFC Calculation based on the Third and Fourth Step

In this step, the priority between the products is determined. If a correct priority based on the sales needs between all of the products is defined, the cost of churners will be declined without any high pressure to production team. There is a lot of method to determine this sequence. The sequences between batches in job sequences is related to "Run Out Time" which is calculated based on the below formula:

$$\text{Run Out Time} = \frac{\textbf{Inventory}}{\textbf{Consumption Rate}}$$

Batch sizes are another factor that should be considered in this model. The Table 9 shows information on the initial specification of each batch size and production to solve and determine the sequences between them.

Now, sufficient time for demand should be investigated by $\frac{\textit{Weekly Demand}}{\textit{Weekly Cepacity}}$ formula.

Table 8. Final results of raw materials planning

asem_no	sta_nam	A	B	C	D	Rudiment Needs	lead time (week)	MOQ	SS	average usage	ROP1	Date	Inventory	Final ROP for 8 weeks
11040770	Board 1	1	1	1	1	1	3	10	2	5	257	776	213	265
11040771	Board 2	1	1	1	1	0	3	10	2	11/25	395	1196	0	395
11040772	Board 3	1	1	0	0	0	3	10	2	0	376	1128	0	376
11040773	Board 4	1	0	0	0	0	3	10	2	0	218	654	34	218
11040774	Board 5	1	0	0	1	0	1	100	30	40	296	336	2	296
11040775	Drive	1	0	0	0	0	4	50	10	12/5	249	1009	11	249
11040776	Contactor1	2	1	1	1	0	4	50	10	1/25	638	2553	14	638
11040777	Contactor2	1	0	1	0	0	4	50	10	11/25	215	871	46	215
11040778	Box	1	1	1	1	0	4	50	10	5	367	1473	36	367
11040779	Screen	1	1	1	1	0	4	50	10	7/5	368	1480	35	368
11040780	Wire	1	1	1	1	0	4	50	10	25	401	1629		401
11040781	Board X	0	0	0	0	4	3	1	2	2	0	1256	57	32
11040782	Board Y	0	0	0	0	3	3	1	2	2	0	156	5	24
11040783	Drive X	0	0	0	0	5	3	1	2	2	0	127	2	40

Table 9. Production information for sequences calculation

Products	Q*	Weekly Capacity	Time of Q* – Week	Weekly Demand	Inventory
A	8	30	1.1	11	30
B	5	25	1	4	30
C	4	30	1	3	2
D	5	45	0.5	3	10
A1	4	10	1.3	2	2
A2	2	13	1.1	2	0
B1	2	14	0.8	1	1
D1	2	14	0.9	1	1

Sufficient time for the demand of product "A" in one week $= \frac{11}{30} = 0.36$

Sufficient time for the demand of product "B" in one week $= \frac{4}{25} = 0.16$

Sufficient time for the demand of product "C" in one week $= \frac{3}{30} = 0.1$

Sufficient time for the demand of product "D" in one week $= \frac{3}{45} = 0.06$

Sufficient time for the demand of product "A1" in one week $= \frac{2}{10} = 0.2$

Sufficient time for the demand of product "A2" in one week $= \frac{2}{13} = 0.15$

Sufficient time for the demand of product "B1" in one week $= \frac{1}{14} = 0.07$

Sufficient time for the demand of product "D1" in one week $= \frac{1}{14} = 0.07$

Total time for demands = 0.36 + 0.53 + 0.33 + 0.2 = 0.99

As the total capacity time for demands is less than 1, it means there is enough time to responsible for all the demand. But the sequences between them are very important.

The sum of batch size is = 1.1 + 1 + 1 + 0.5 + 1.3 + 1.1 + 0.8 + 0.9 = 5.9 week

Now, the continuance time for each product should be calculated. The Table 10 shows continuance time based on the $\frac{\textbf{Inventory}}{\textbf{Weekly Demand}}$ formula.

As the results show, the continuance time of A2 product is less than others. So, A2 should be produced

Table 10. Continuance time for each product

Products	A	B	C	D	A1	A2	B1	D1
Continuance time	$\frac{30}{11}=2.72$	$\frac{30}{4}=7.5$	$\frac{2}{3}=0.66$	$\frac{10}{3}=3.33$	$\frac{1}{2}=0.5$	$\frac{0}{2}=0$	$\frac{1}{1}=1$	$\frac{1}{1}=1$

at first because of the high priority. After A2, C should be produced. The Table 11 shows the continuance time for each batch:

As the results show, at the next stage B1, D1 and A1 should be produced (equal to Q^*). This priority is determined by their continuance time.

Table 11. Continuance time for each product

Products	Inventory	continuance time – week
A	30 – 11 (0.8)	21.2
B	30 – 4 (0.8)	25.8
C	2 – 3 (0.8) + 4	3.9
D	10 – 3 (0.8)	7.6
A1	2 – 2 (0.8)	0.4
A2	0 – 2 (0.8) + 4	2.4
B1	1 – 1 (0.8)	0.2
D1	1 – 1 (0.8)	0.2

4. Conclusion

Production and material planning are one of the most important parts of the manufacturing systems. If the best method for each production system isn't chosen, that system will encounter to a lot problems such as increasing their costs, shortage of material, unjustifiable delays, etc. So, production managers should consider this major as an important and essential part of their system. It's imperative to consider the best methods for planning in proportion to each production systems. In this model, an integrated method is clarified in order to increase the responsibility of production department for both their routine and customers' orders. All of the results in stage 3.5 – 3.6 are calculated for both types of push and pull systems. Furthermore, all of the restrictions are considered in order to improve the productivity and use the resources efficiency.

5. References

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