Manufacture of a Biodegradable Detergent on Small Scale

Abdulla A.Aziz A.Majeed abuwaelhb@yahoo.com
Faculty of Engineering,
I Department of Mechanical Engineering,
University of Aden, Yemen
Aden, Yemen

Jairam Singh jsinghaden@yahoo.com
Faculty of Engineering,
Department of Mechanical Engineering,
University of Aden, Yemen
Aden, Yemen

Abstract

This paper deals with an aggregate planning for a small scale production unit using a network flow model for full utilization of its capacity to meet the changing forecasted demand .The formulation of the problem is done by using the given inventory capacity with backorders by making a trade-off among inventory costs , backlog costs, production and subcontracting costs. The total cost function and the constraint inequalities were developed assuming the cost functions to be linear. The parameters of objective function and the constraints were estimated from the economics of the plant. The values of the work force, overtime, backlog, amount subcontracted were determined for a planning horizon of six months using an LP computer package. This method of production scheduling took care of the fluctuating demand utilizing the full capacity of the plant.

Keywords: Production scheduling, Operations Management, Supply chain Management.

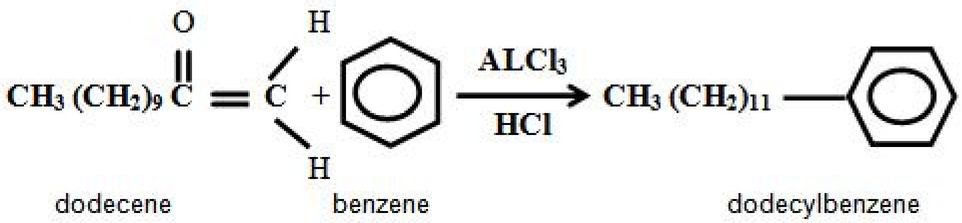
1. INTRODUCTION

The goal of the IJCSS is to publish the most recent results in the development of information technology. Soaps are the earliest form of detergents, though at present, the term detergent is used for synthetic detergents derived from petroleum products. Due to tremendous strides in petrochemical industries, propylene became available which was polymerized to propylene tetramer that became the major feedstock for the manufacture of synthetic surfactant known as Linear Alkyl Benzene Sulphonate (LABS). To improve the detergency of powders, certain other components known as builders, synergizers, fillers and brighteners, etc. are also added. The surfactants have molecular structure that have hydrophilic groups on one end and hydrophobic groups on the other end which imparts the special characteristics of soil removal from the surface of the clothes [4,5].

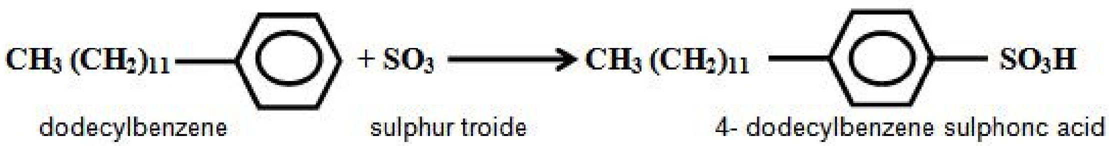
2. The Production Process of an Anionic Detergent

Synthetic detergents are cleansing agents which have all the properties of soaps, but which actually does not contain any soap. These can be used both in soft and hard water as they give foam even in hard water some of the detergents give foam even in ice cold water.

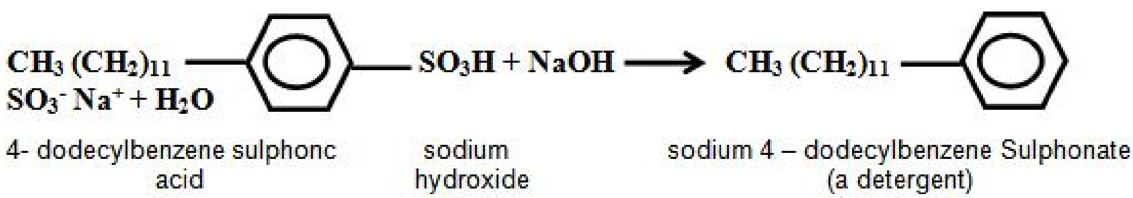
The propylene tetramer dodec-1-ene can be made to add onto a benzene ring in presence of hydrogen chloride and aluminum chloride catalyst - a variation of Fridal-Crafts reaction as shown below:



The dodecylbenzene is sulphonated by refluxing it with concentrated sulphuric acid. The form of sulphuric acid is (HO)2 SO2 i.e. an oxoacid with two –OH groups and two oxygen atoms attached to a central sulphur atom. The actual electrophile is SO3 and the overall reaction may be represented as



This is neutralized by sodium hydroxide to form the sodium salt, which is the detergent.



Here, the reactions used are essentially those which can be carried out in the laboratory, although the conditions vary somewhat. The sulphur trioxide gas (hard to handle in the laboratory) is used rather than sulphuric acid for the sulphonation step. This detergent makes up around 10% by weight of most commercial washing powders. This detergent sodium 4-dodecylbenzene sulphonate has the 12-carbon side chain attached by a Friedel-Crafts reaction is biodegradable. Bacteria such as Escherichia coli can degrade this detergent.
Small scale production of detergent powder is done by mixing 15 to 40 percent active surfactant known as acid slurry with rest of the additives in an Amalgamator and a slurry milling machine. Then it is pulverized in a pulverizer. Then the stuff is ground in either a disintegrater or a centrifugal type of grinding machine. Then packaging is done as required by the consumers [5].

3. Aggregate Planning for Production

An aggregate planning is a process by which company determines levels of production capacity, subcontracting, inventory, stock outs and even pricing over specified time horizon, the goal of aggregate planning is to satisfy demand in a way that maximizes profit. Generally, the demand rate varies over time and the associated problem becomes a dynamic planning problem [1,2,3,6] but it is assumed to remain the same during a fixed period stated in the planning time horizon.

The following are some of the alternatives available for planning to meet the fluctuating demands.

1. Build inventories during the period of peak demand in anticipation of higher demand rates later in the planning periods.
2. Carry backorders during the periods of peak demands.
3. Use overtime in peak periods or under time in slack periods to vary output while holding workforce and facilities constant.

4. Use subcontracting in peak periods.
5. Vary capacity by changing the size of the workforce through hiring and firing.
6. Vary capacity through changes in plants and equipment. Since we typically are concerned with planning horizon less than a year, we usually shall assume that facilities are fixed and thus this alternative is not available to the planner.

The optimal combination of these alternatives involves proper trade-offs between the following types of costs:

1. Production costs which include any out-of-pocket costs that is associated with production rate.
2. Inventory holding costs.
3. Shortage losses associated with backorders and lost sales.
4. Costs of increasing and decreasing workforce levels. These include hiring and training costs and separation pay and other losses associated with firing or laying off workers.
5. Costs of deviating from normal capacity through use of overtime or under time.

4. The Network Flow Model

In general, the fundamental trade-offs available to an aggregate planner are among the following:

1. Capacity (regular time, overtime, subcontracting).
2. Inventory.
3. Backlog / lost sales.

An aggregate plan that decreases one of these costs typically results in an increase of the other two. In this sense, the costs represent a trade-offs. To lower inventory cost the planner must increase capacity costs or backlog costs. Arriving at a most profitable trade-offs is the goal of an aggregate planning [8,10]. It is interesting to observe that the aggregate planning problem can be conceptualized as a network model with backorders as indicated in the network flow diagram in Fig.1.

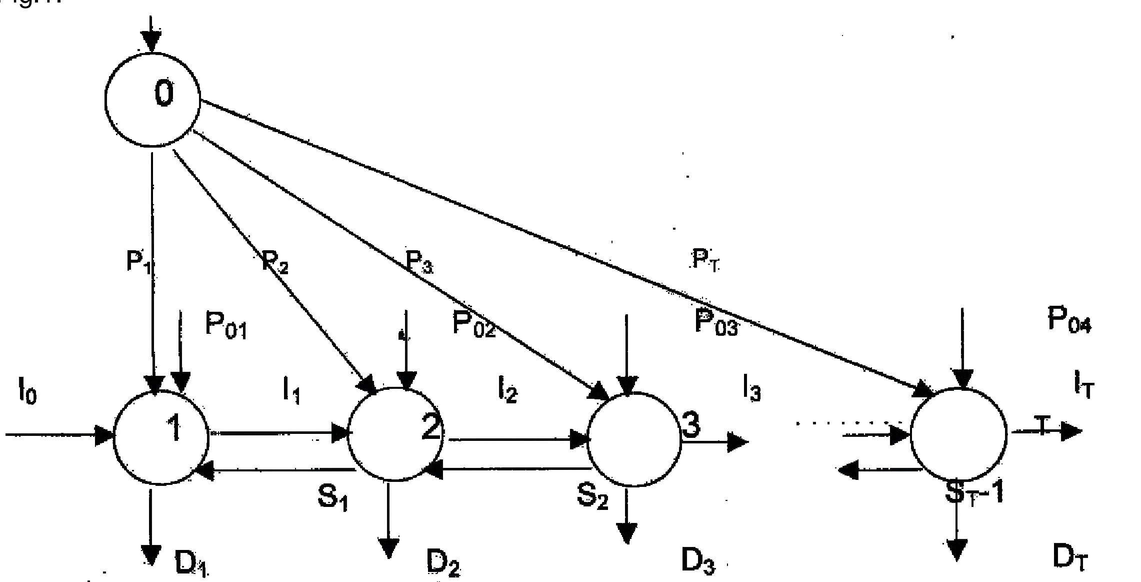


FIGURE 1: Network Flow Model With Backlogging

4.1 Decision Variables

The following decision variables are defined for the aggregate planning model:
W_t = Workforce size in man - hours for the month t; t = 1, 2, 3…., T.
H_t = number of employees hired in man-hours at the beginning of the month t; t=1, 2,…..T.
L_t = number of employees laid off at the beginning of the month t; t = 1, 2….., T.
P_t = number of units produced in month t, t = 1, 2,…..T.

I_t = inventory at the end of the month, t = 1, 2,…..,T.
S_t= number of units stock out / backlogged at the end of month t; t = 1, 2,…..,T.
P_{st}= number of units subcontracted for the month t; t = 1, 2,….,T.
O_t= number of overtime man-hours in month t; t = 1, 2,…..,T.

4.2 Parameters of the Problem

C_t= unit material cost in the period t; t= 1, 2,……,T.
h_t= inventory carrying cost per unit held in the period t; t = 1,2,…….,T.
TT_t = backorder cost per unit carried from period t to t +1.
m = number of man-hours required to produce one unit of product.
L_t = cost of one regular labour per man-hour.
e_t =cost of hiring and training per unit of labour.
e^t = cost of laying off one worker.
D_t = demand in the period t.
C_{st}= cost of subcontracting per unit.

4.3 Formulation

The values of demand, D_t, are specified by the demand forecast which is fluctuating each month of the planning horizon [7,9]. The objective function is to minimize the total cost incurred during the entire planning horizon. The cost incurred includes regular labour cost, overtime labour cost, cost of hiring and training, cost of laying off, cost of holding inventory, cost of stocking out, cost of subcontracting and material cost. The objective function turns out to be

$$z = \sum_{t=1}^{T} [\, L_tW_t + e_tH_t + e^tL_t + 1.5\, L_tO_t + h_tJ_t + \pi_tS_t + C_{st}P_{ot} + C_tP_t \,] \quad \textbf{(1)}$$

to be minimized subject to the following constraints. It is intended to give a high level customer service having met all their demands.

i. Workforce constraint

The workforce size W_t in any period t, is dependent upon the workforce size in the previous period (t-1) and number of workers hired in the period t and the number of workers fired in the period t. Therefore

$$W_t = W_{t-1} + H_t - L_t \quad \text{for } t = 1,2,\ldots\ldots T.$$

The starting workforce is given to be W_o. Then

$$W_t = W_o + \sum_{t=1}^{T} = (H_t - L_t) \quad \textbf{(2)}$$

ii. Capacity Constraint

In each period, the amount produced in house cannot exceed the capacity of the plant available including overtime. This constraint limits the internal production based on three shifts and overtime subcontracted production is not included in this constraint. Let us say that the total production of the plant is X units per month and total man-hours required per month are Y. Then man-hours required per unit of production is Y/X

Therefore,

$$P_t <= Y/X\, W_t + Y/X\, O_t \quad \textbf{(3)}$$

iii. Inventory balance constraint

This set of constraints balances inventory at the end of each period. Net demand for the period t is obtained as a sum of current demand D_t and the previous backlog S_{t-1} .This demand is either filled with the current production P_t and/or subcontracted from outside, P_{st} and the previous inventory, $I_{t-1.}$ In some cases, we make a provision of inventory in the period t, I_t and some backlog in the period t, S_t. Hence, the constraint turns out to I be

$$I_{t-1} + P_t + P_{st} = D_t + S_{t-1} + I_t - S_t;\ t=1,2,\ldots..\ T. \quad \textbf{(4)}$$

The starting inventory I_0, may be known and sometime the ending inventory may also be required.

iv. Overtime constraint

This set of constraints requires that no employee should work more than a specified man-hours as overtime each month for efficient working. Let us say that not more than I0 percent of the total man-hours is allowed as over time.

Then

$$O_t = 0.10\, W_t \quad , t = 1.2, \ldots \quad T \qquad \textbf{(5)}$$

v. Backlog constraint

Sometimes more backlog creates a lot of problem to the reputation of the company. Therefore, some restriction is imposed on the level of backlog but it is not a mathematical requirement at all. Let us say that not more than 10 percent of the total demand can be backlogged, then the constraint assumes the form as.

$$S_t = 0.10\, D_t \,;\, t = 1.2, \ldots T. \qquad \textbf{(6)}$$

vi. Workforce Constraint

Generally all the production organizations have some permanent workers (skilled and unskilled) and they work minimum for one shift and maximum for three shifts. In this problem, not less than one shift is desired as a special case.

Therefore,

W_t => man-hours available per month per shift **(7)**

vii. Warehouse constraint

Another constraint is the capacity of the warehouse.

$$I_t = c_w \qquad \textbf{(8)}$$

The problem boils down to minimizing Eq. (1) to subject to the conditions stated in Eqs. (2) to (7). The values of the parameters are estimated from the economics of the plant.

5. Case Study

An aggregate planning of a Detergent Manufacturing Company for a plant Capacity of 12.5MT per month per shift.

An aggregate plan has been developed for this company that has to satisfy the following forecasted demand, as given in the Table 1.

Month	Forecasted Demand, kg.
July	16,000
August	30,000
September	32,000
October	38,000
November	22,000
December	22.000

TABLE 1: Forecasted Demand of the company

The required workers and their wages, the raw materials required for manufacture to the full capacity of the plant per shift are worked out as shown in Appendix 1. The company has a starting inventory in the month of July of 10,000 kg.

Estimation of the Parameters

Estimation of regular labour wages

From the plant economics [5] (Appendix I), it is obvious that five workers are paid at the rate YR 40,000 per month for working 8 hours a day and 25 days a month. Therefore labour wage per man-hour, L_t

L_t= YR 40/man-hour.

Overtime cost is one and a half times the regular cost.

Cost of hiring and firing
The cost of hiring and training a worker is one and a half times the normal wage rate i.eYR60.00 per man-hour and cost of firing a worker is double that of hiring. Therefore

e_t =YR 60 per man-hour.
e^t =YR 80 per man-hour.

Estimating the cost of Inventory and stock out
The rent of the store including watchman's wages is YR 30,0000/ for storing 15000kg of detergent. Therefore, inventory-holding cost per kg per month is YR 2/kg/month. If the demand is not met, it is backlogged which is estimated to cost YR 80 kg including loss of goodwill.

Estimation of material cost and cost of subcontracting
It is clear from appendix I that the cost of raw materials for producing 12,500 kg of detergent is YR 400,600. Therefore,

C_t = 400,000/12,500 =YR 40 per kg.

It is assumed that if we get the detergent from a sister concern, it will cost more the double, that is,

C_{st}= YR 100/kg

Determination of the decision variable
The complete formulation can be written as follows after subsisting the values of ft parameters.
To minimize

$$Z= [40W_t + 60H_t + 80L_t + 60O_t + 21_t + 80S_t + 40P_t + 100P_{st}] \qquad \textbf{(9)}$$

Subject to

Workforce: $W_t = W_{t-1} + H_t - L_t$ **(10)**

Production Capacity: $P_t <= 12.5\ W_t + 12.5\ O_t$ **(11)**

Inventory: $I_{t-1} + P_t + P_{St} = D_t + S_{t-1} + I_t - S_t$ **(12)**

$W_t >= 1000$ **(13)**

Inventory Capacity: $I_t <= 15000$ **(14)**

Backlog: $S_t <= 0.10\ D_t$ **(15)**

The objective function and the constraints are linear functions of the variables. Therefore, the solution to the problem can be obtained by solving it as a linear programming problem [9]. A standard L.P.P package is available as TORA which has been used to find the solution as given below. The solution of the problem from July to December for the entire planning horizon is given in the Table 2.

Period	Inventory I_t	Hired H_t	Laid off L_t	Work force W_t	Overtime O_t	Backlog S_t	Production P_t	Subcontract P_{st}
0	10000	0	0	0	0	0	0	0
1	0	0	0	1000	0	0	6000	0
2	0	0	0	2400	480	0	30000	0
3	0	0	0	2400	480	2000	30000	0
4	0	0	0	3000	0	500	37500	0
5	0	0	0	2000	600	0	22000	0
6	0	0	0	2000	600	0	22000	0

TABLE 2: Aggregate plan for 6 month-horizon

6. Results and Discussion

The forecasted demand of the detergent in a detergent manufacturing company is given in Table 1. This shows that the demand is fluctuating every month and it varies from 16000 kg/month to 32000 kg/month. In this production scheduling problem a number of decisions variables are involved as discussed in the section 4.1. A linear programming model was developed including a decision variable known as subcontracting, P_{st}. After solving the formulated linear programming problems, the complete solution is given in Table 2. The results show that the firm can manage the demand by manipulating the overtime variable, O_t, and subcontracting is not required. In order to meet the demand if subcontracting variable is high, then cost of production will increase. This may demand the expansion of the plant capacity instead of subcontracting. This type of production scheduling will help in understanding whether expansion is economical or not. The case study considered here as an example shows that subcontracting for given six month's horizon of scheduling is zero. This indicates that at the moment the capacity expansion may not be desirable but in future if the demand increases then an analysis of a trade off between subcontracting and expansion of the plant is required to take appropriate decisions.

7. Conclusions

Surprisingly, many companies do not go for an aggregate planning instead rely on orders from their distributors or warehouses to determine their production schedules. These orders are actually driven either by an actual demand or through inventory management algorithms .If a company has no trouble in efficiently meeting the demands this way, then lack of aggregate planning may not significantly harm the company. However, when the capacity utilization increases and capacity becomes an issue, relying on orders to set the production schedules can lead to a capacity bottleneck. When utilization is high, the probability of supplying all the orders as they arrive is low. Therefore, manager should resort to aggregate planning to best utilize the capacity to meet the forecasted demands. Aggregate plans are based on forecasts of future demands that are always subject to errors. Therefore, the aggregate plans need to have some flexibility. The network flow method of aggregate planning helps to develop an aggregate plan formulation amenable to a linear programming solution which involves sensitivity analysis. This provides a tool to calculate the cost of expanding the capacity during peak periods clubbed with the costs when the demands are lower than expected. This might lead to postponing the capacity expansion decision. This paper shows that an aggregate planning will be a powerful tool to manage periodic higher demands without expanding the capacity of the plant.

8. References

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11. Appendix

Manufacturing Economics of 12.5 WIT per Month Capacity Plant [2]
Basis:
Rated capacity: 500 kg per day.
Number of working days : 25 days per month.
Number of hours per shift: 8
Currency: Yemeni Rials.

Cost of Land Building

Land area, 1000 square meter @ YR 220 per square meter:	YR 220,000
Covered area, 50 square metre @ 4.800YR per square metre:	YR 240,000
Boundary wall, gate and miscellaneous:	YR 24,000
Total	YR 484,000

Plant and Machinery

1. Amalgamator, 150 kg per shift; No.1:	
2. Milling machine,150 kg per shift, No. 1:	
Gross amount for items 1 and 2:	YR 280,000
3. Empty drum for storage, @ YR 800per drum, No. 5:	YR 4,000
4. Neutralizer (Kettle of stainless steel):	YR 60,000
5. Blender (Semi- automatic, capacity: 100 kg per hour ,No. 1:	YR 120,000
6. Pulverizing machine , capacity :100 kg per hour ,No. 1:	YR 100,000
7. Weighing machine, No. 1:	YR 40,000
8. Miscellaneous items, like blowers, trolleys and bag sewing m/c:	YR 60,000
9. Small Furnace:	YR 20,000
10. Laboratory equipment:	YR 20,000
Total	YR 724,000

Other Fixed Assets

Installation costs for water, electricity and fuel	YR 20,000

Total Capital Cost

Land and building	YR 484,000
Plant and machinery	YR 724,000
Other fixed assets	YR 20,000
Total	YR 1,228,000

Raw Materials Required per Month

1. Acid slurry(LABS),575 kg @ YR 720 per kg:	YR 92,000
2. Sodium triphosphate,1175 kg @ YR 88 per kg:	YR 103,400
3. Carboxy methyl cellulose,375 kg @YR 600 per l:	YR 225,000
4. Optical whitening agent 5 kg @YR 640 per kg:	YR 3,200
5. Foam booster 25 kg @ 160 per kg:	YR 4,000
6. Sodium silicate 125 kg @ YR 20 per kg:	YR 2,500
7. Sodium sulphate 412.5 kg @ YR 32 per kg:	YR 13,200
8. Acid slurry * 300 kg @YR 160 per kg:	YR 48,000

9.	Soda ash 1000 kg @ 28per kg:	YR 42,000
10.	Sodium silicate * 1000 kg @ YR 16per kg:	YR 16,000
11.	Marble chips 7200 kg @ YR 4per kg:	YR 28,800
12.	Packaging material:	YR 25,000
	Total:	YR 400,600