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OPTIMAL PLANNING OF TECHNOLOGICAL FOW LINES

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Abstract: *In paper an aggregate planning models as linear program will be formulated to plan the optimal use of technological flow lines (FL). The use of aggregate planning for various tasks of planning the optimal economic order quantity and to estimate of rational use of resources for FL is demonstrated. On basis of the proposed model different cases for optimal planning of continuous flow processes of existing FL-s are investigated. The results of analyzes different situations are given. The goal is not so much to provide specific solutions to given particular problems, but rather to illustrate a problem-solving approaches and use of computer instruments.*

Keywords: *Aggregate planning. optimal planning, technology lines.*

1. INTRODUCTION

Most discrete products manufacturing plants make at least partial use of some kind of flow line (technology line). We can classify Flow Lines (FL) by process structure as follows [1].

- Disconnected flow lines. Product batches are produced on a limited number of routings. The individual stations within lines are not connected, so that inventories can build up between stations.
- Connected flow lines. This is classic moving assembly line. Product is fabricated and assembled along a rigid routing connected by a paced material handling system.
- Continuous flow processes. Continuous product (food, chemical, etc) flows automatically down a fixed routings.
- Agile or flexible flow lines for modular products (FFL). To respond to the challenge of agile manufacturing, companies are striving to meet the changing market requirements at a low cost. The ability to produce a variety of products is a meaningful benefits of use the flexible flow lines.

The main purpose of a FL is to provide quality products in a timely and competitive fashion. A FL planning process consistent with this goal is the following.

- The customer determines the Product. Mixes, volumes, cycle times and demand forecast.
- The products determine the processes.
- The processes determine a basic set of machines.
- The machines determine the facilities needed to support them.
- The facilities determine the overall structure and size of the FL.

2. BASIC MODEL FOR AGGREGATE PLANNING

The objective of this research is to develop an appropriate and useful model for analyzing and designing of FL based on use of aggregate planning model [3]. To do this, we attempt to describe the mathematical model of FL, to define the objectives, constraints and alternatives for the project of FL.

The design procedures for FL planning are unlikely to result in a balanced line. The reasons are as follows:

- An unbalanced FL with distinct bottleneck is easier to manage and exhibits better logistical behavior than corresponding balanced lines.
- The cost of capacity is typically not the same at each station, so it is cheaper to maintain excess capacity at some stations than others.
- Capacity is available only in discrete-sized increments, so it may be impossible to mach capacity of a given station to a particular target.

In order to meet the demand for a variety of products without holding an excessive level of inventory, multi-product FL are used, based on the combination of modular components [2].

It is assumed that the generalized manufacturing process structure of a product family has different alternatives for different products. Different set-ups of FL allow to produce the whole family of products.

It is assumed also that the manufacturing process structure of a modular product family includes a basic structure and a variant structure. Each product in a product family shares the same basic structure and differs from others in the variant structure. The operations in the **basic structure** are referred to as **basic operations** and the operations in the **variant structure** are referred to as **variant operations** (Fig1**)**.

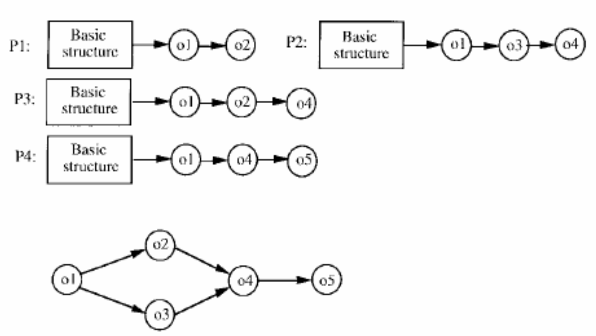

Fig 1 Generalized structure of manufacturing process of product family and alternative structures of FL (from [2])

An FL has to be reconfigured efficiently to accommodate changes in the product mix and should be designed to fit the structure of Product Mix.

Normally, the basic operation structure forms a major part of the FL shared among products and remains relatively stable. The changes in a product structure are accomplished by changing the variant operations structure to create product variants to meet the diverse customer requirements.

2.1 A linear program model for FL planning

As for example we have modeled a real model for a mayonnaise production in food industries. We use a linear program formulation of the EOQ problem for mayonnaise FL. The objective for FL is the profitability of use the FL. The objective functions includes as components:

- Profit from product sold
- Production cost
- Setup cost
- Cost to hold one unit of inventory
- Yield loss cost
- CIP (Clean in place) system cost

For every period we have demand forecast and workstations capacity constraints. For simplicity, we assume that demand represents customer orders that are due at the end of the period and we neglect randomness of model parameters and yield loss.

For modeling purposes to develop the EOQ model for computing optimal production lot sizes for FL following notations are defined:

N = Number of products

M = Total number of workstations

$p_{t,i}$ = Number of lots for product ***i*** in period t

d_{it} = Demand for product i in period t

h_i = Holding cost to carry a unit of inventory for one period; for example, if holding cost consists entirely of interest on money tied up in inventory, then $h_i = i * C_i / 52$, where i is the annual interest rate and periods correspond to weeks. The holding cost for one period is determined as $h_i * (I_{it} + I_0)$. Days inventory in mayonnaise production are very low due to a short shelf-life. Initial inventory and security stock are only used in calculations.

c_{jt} = Capacity of workstation j in period t in units consistent with those used to define τ_{ij}

r = Profit per unit product sold

rw_i = Raw material cost per unit produced

s_i = Selling price of product i.

T_i = Maximum available number of minutes in one day for producing product i. In our case this is 960 minutes, we assume that we can produce 16 hours per day.

τ_{ij} = Processing time of ith product at station j, $i=1,\ldots,N;\ j=1,\ldots,M$

Cji = Production cost (not accounting inventory costs) product ***i*** in FL station j

λ_{im} = Set-up time of i'th product at station m, $i=1,\ldots,N;\ m=1,\ldots,M$

A_{im} = Set-up cost for product ***i*** in FL station ***m***

w_i = CIP system cost for one shift. It is a costs, related to the central wash system for mayonnaise pipelines. There are included water cost, chemicals cost, labor cost, etc.

y_i = Yield loss cost for one shift. It is a cost of production losses, filling losses, product losses inside the pipeline, production flaw, etc.

CIP system cost for one batch

y_i = Yield loss cost for one batch

X_{it} = Quantity of product i produced during period t (assumed available to satisfy demand at end of period t)

S_{it} = Quantity of product i sold during period t (we assume that units produced in t are available for sale in t and thereafter)

I_{it} = Inventory of product i at the end of period t (after demand has been met); we assume I_{i0} is given as data.

Xp_{it} = Number of products i in batch during period t

Xpm_{it} = Maximum number of products i in batch during period t

T_i = Maximum period of production for product *considering hygiene point of view.*

Note that I_{im} and I do not include the transportation time between two stations, it can be either ignored or included in the processing time of a product. In our case transportation time is included in the processing time.

To forecast the demands for future periods different smoothing techniques could be used. Excel proposed different instruments for analysis of forecast of future market demands [1]. The forecasts of market demand for different products are not shown in this paper.

The problem what we have in mind was that of a company producing various products in one technology line and where switching between products entails a costly setup. And in our practical example there are also added yield losses and CIP system costs.

We can give a linear program formulation of the problem to maximize net profit minus manufacturing and set-up costs, inventory-carrying cost, yield losses, CIP system costs and subject to sale and capacity constraints as [3]:

$$\text{Max} \sum_{t=1}^{tl}\sum_{i=1}^{N}\sum_{j=1}^{M} s_i * S_{i,t} - (\tau_{i,j} * C_{j,i} + rw_i) * X_{i,t} - h_i * (I_{i,t} + I_{i,o}) - Xpc_{i,t} / Xp_{i,t} * (\lambda_{i,m} * A_{i,m} + w_i + y_i)$$

subject to:

$S_{it} \le d_{it}$ *for all i,t*

$\sum_{i=1}^{N} \tau_{i,j} * X_{it} \le c_{jt}$ *for all j,t*

$I_{it} = I_{it-1} + X_{it} - S_{it}$ *for all i,t*

$I_{it} \ge s_{it}$, *for all i= 1,…,N;t=0…tl*

$Xp_{it} * max(\tau_{ij}) \le T_i$ *for all i,t*

X_{it}, S_{it}, $I_{it} > 0$ *for all i,t.*

X_{it}, S_{it}, I_{it} *are integer*

There exist a non-linearity in model if we try to optimize both the volume of production X_{it} and number of lots $p_{t,i}$. To analyse of the influence of different parameters of FL to the profit, to estimate the EOQ, etc the simulation of the proposed model for different fixed number of lots $p_{t,i}$ could be used. In our example most profitable production should be two shifts in one day. In this cases the set-up cost, the yield loss, the CIP system cost are most minimal. As for a strong competition between different food-industries, they have many products in their portfolios and very often batch sizes are very different. Also in our case there are huge variations in batch sizes. It is reasonable to use linear program formulation to analyze correlations between batch sizes and profit, to analyse the performance indicators of FL. One way to use linear program is to use Excel Solver. Solver is part of a suite of commands sometimes called what-if analysis tools. With Solver, you can find an optimal value for a formula in one cell — called the target cell — on a worksheet.

Excel Solver is a good tool for a production manager and not only, also according to this model there can be made strategical decisions for a future prognosis purposes. Very often management don't have exact numbers for production and with the help of production manager there are chance to analyze different situations while using LP model in Solver. Our model is actually based on a real problem in mayonnaise production.

As for working with different ERP systems, which at the end can actually also give the same result as LP model in Excel Solver, there can be said that use of Excel Solver for planning is much more flexible than any ERP system and could be used as an additional computer instrument to ERP.

2.2 Analysing results

On basis of the proposed model different cases for optimal planning of continuous flow processes of existing FL-s are investigated.

We suppose that there exist different technically and economically available options of FL we can change, that that there are possibilities to change the characteristics of the technological processes. We propose to use the basic model of FL to a heuristic search for determining maximum profit options and characteristics of the technology process.

To illustrate this approach we use as example the simulation of influence the number of lots to the profit.

To describe the practical cases the additional restriction related to the management of production must be included. In figure 2 for the FL of food industry the dependence of profit from the production volume with the same receipt (set-up) is given.

In our example the most profitable way is to produce straight two shifts in a FL. Therefore we can save some money in set-up costs, in yield loss and in CIP system. Very often in food industries you can produce only one specific product in a FL. If there are need to produce other products, then there is needed completed cleaning and washing, which means that there are yield losses and set-up costs, because lines should be reconfigured.

In our example we made model for mayonnaise production and in this specific product there are also some unusual constraints. Shelf-life is also very important issue while planning production in mayonnaise production. As in mayonnaise production there is no heating, only cold mixing, then the product is very vulnerable from bacteria side. This is the main reason why mayonnaise shelf-life is not more than 90 days. Usually it is 70 days, and this is a serious argument while planning production. There are basic rule for food-industries. 2/3 of a shelf-life should be left before the product has reached to wholesaler. In mayonnaise production, days inventory should not be more than 20 to 30 days, depending of product type.

In hygiene point of view there is also one other constraint for planning. There are very often limitations in maximum batch sizes. That means in our case we can produce two shifts in a row, and then we need to make again completed cleaning for production line. In this model we put down the constraint that batch size should be less or equal to 16000pcs in one production day.

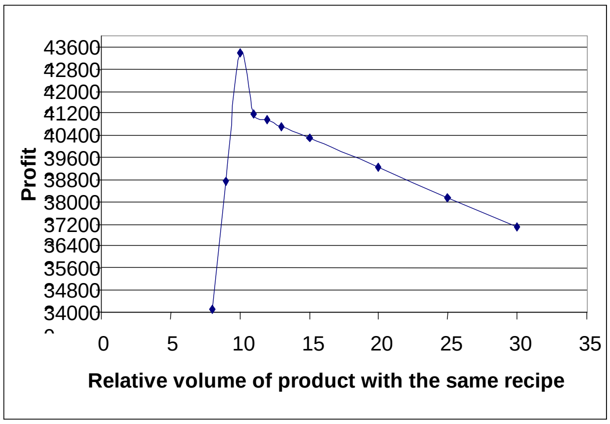

Figure 2. Change in profit due to increase of volume of product (lot size)

Sensitivity results we derived above for the EOQ model imply that the error introduced by the changes of the main parameters of model will not be excessive.

On figure 3 the total profit as a function of number of lots for different ratios of processing costs to set-up costs are represented. We have increased the set-up cost, yield loss cost and CIP cost in three different situations. We have increased costs hypothetically 5%, 10% and then 15%. The figure shows the results of simulation of the dependence of optimal number of lots from the ratio of processing cost to set-up cost (included also yield losses and CIP cost).

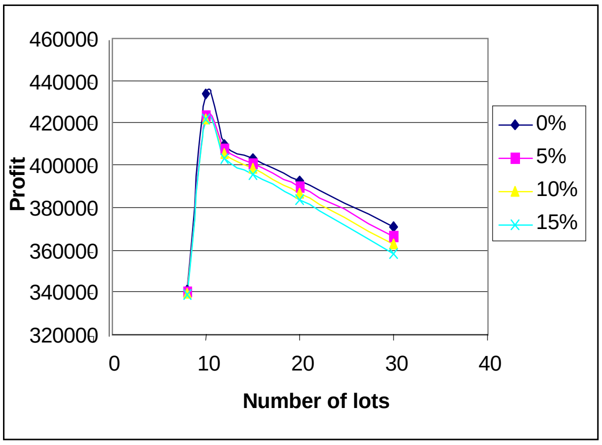

Figure 3. Analyze of the EOQ for different unit manufacturing and set-up cost ratio.

Figure 3 shows the loss of profit if there would be any increases in costs.

We suppose that there exist different technically and economically available options of FL we can change, that for example we can modify the FL by adding computer-controlled equipment to minimize the yield losses. For example in mayonnaise production we have implemented scale computer indicators (SCI). Basically they are automatic scales which are connected to the server. The SCI works as it follows: the worker choose a receipt, then inserts batch number and work order number. Next the worker moves on to component field, where SCI shows already the first component needed for weighing. Weighing procedure is simple, that worker puts needed component on a weighing platform and pushes ENTER. SCI has tolerance while weighing components. That means that program administrator puts tolerances which cannot be broken. If the worker misses weighing procedure more than given tolerances, there is no change to register the weighing result. These SCI have been very useful while reducing raw material losses in mayonnaise production. Thanks for the SCI, there are decreased raw material losses from 3% to 1%.

To compensate the yield losses we proposed in initial aggregate planning model to use the safety stock. For this purpose the average yield loss rate was used. This is not enough to plan an effective yielding strategy for continuous FL and we must consider more precisely the yield losses [1]. The need of extra raw material to compensate for yield losses must be considered. In our example the accuracy of mayonnaise yield losses is satisfied and therefore it is not used in our model. But generally in production we can assume that $\alpha_{im}, i = 1,....,N, m = 1,....,M$ represent the fraction of product that is lost to scrap at workstation m for product i. If we plan X_{it} units of product to come out of FL then considering yield losses we have to release $X_{it} / \prod_{m=1}^{M}(1-\alpha_{im})$ units of product into FL.

To compensate the yield losses we must change the initial model by substituting the constraints restricting resources: $\sum_{i=1}^{N}\tau_{i,j} * X_{it} / y_{i,j} \le c_{jt}, i = 1,...,N; j = 1,...,M$ for all t,

where $y_{i,j} = \prod_{j=j}^{M}(1-\alpha_{i,j})$ = cumulative yield losses from workstation *j* onward (including station *j*).

In objective function we must consider that the scrapping product in the late of the process is more costly as in the first workstations. To consider the yield losses the formulas of costs of raw material must be substituted in objective function with $rw_i * X_{i,t} / \prod_{m=1}^{M}(1-\alpha_{i,m})$ and production cost with: $\sum_{j=1}^{m} C_{j,i} * \tau_{i,j} / y_{i,j}$. For simulation the fractions $\alpha_{i,m}$ are input variables, the cumulative yield losses $y_{i,j}$ could be calculated for each workstation before the optimization.

3. CONCLUSION

In paper an aggregate planning models is proposed to plan the optimal use of technological flow lines (FL). We suppose that there exist different technically and economically available options of FL we can change. We propose to use the basic model of FL to a heuristic search of maximum profit options and characteristics of the technology process. The estimation of the optimal economic order quantity and to analyze of rational use of resources for FL are examples of use the proposed model. On basis of the proposed model different cases of continuous flow processes for planning existing FL-s are investigated.

We figured out that Excel Solver is a suitable computer tool for working with LP and it is also very flexible. As we saw in our example of mayonnaise production there were many different constraints which characterize the complicated planning task for FL. But the simulated model showed clearly how to earn the biggest profit.

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