

A Methodology for Optimal Selection of Product/Customer Mix in Manufacturing Industries

FELIPE ALBERTO SIMAS DONATO

Axia Consulting

Av. Nações Unidas 12551, 18nd floor

Zip Code 04578-903

São Paulo, SP, Brazil

Phone: 55-11-3043-7430

Fax: 55-11-3043-7430

email: felipe.donato@axiaconsulting.com.br

SÉRGIO FERNANDO MAYERLE

Departamento de Engenharia de Produção e Sistemas

Universidade Federal de Santa Catarina

Campus Trindade, Florianópolis, Brazil

Phone: 55-48-3721-7036

Fax: 55-48-3721-7075

email: mayerle@deps.ufsc.br

JOÃO NEIVA DE FIGUEIREDO

Saint Joseph's University

Haub School of Business Department of Management

5600 City Avenue

Philadelphia, PA 19131

Phone: 610-660-3138

Fax: 610-660-1229

email: jneiva@sju.edu

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Abstract

A two-stage multi-period optimization methodology for aggregate production planning encompassing component supply management and final assembly is developed. This methodology enhances the efficiency of Sales and Operations Planning (S&OP) through a linear programming model that uses cost and profit contribution data to select the optimal product and customer mix. An illustrative application improving the medium-term operations strategy of a Brazilian mechanical manufacturer is presented.

Keywords: Aggregate production planning; Linear programming; Product mix; Client mix; S&OP.

1. Introduction

Tight linkages between companies' strategic planning processes and factory floor tools are a necessity in today's competitive environment in which close alignment between formulated strategic objectives and functional area initiatives is a potent competitive weapon. These linkages among the various levels of planning, from the strategic level to the plant-floor scheduling level, including medium-term planning such as Sales and Operations Planning (S&OP), are extremely important for consistency of goals and effective execution. Production planning and control systems are important for operations management in any manufacturing company not only because they provide the necessary information for raw materials purchasing and short-term production planning, but also because their output provides information that supports broader strategic decisions, such as capital investments and marketing expenditures, for example.

Production planning and control systems have yet another important strategic role, as a support to medium-term planning. Expected sales demand in the ensuing 6 to 24 month period is the first input for medium-term planning, the output of which is the production and inventory plan for the period, which feeds into longer term financial planning. Financial goals such as gross profit, operating income, and free cash flow generation are linked to this planning level. Important decisions, such as the mix of products to be produced, the use of overtime, the safety inventory levels, and investment needs are linked closely to medium-term planning.

Although the academic literature has for decades underlined the importance of the aforementioned linkages between different levels of planning, there is a dearth of specific mathematical tools and methodologies that support them. This paper seeks to fill that gap by proposing, developing and applying an uncomplicated optimization model that does just that. The paper describes a linear programming model to optimize the tradeoffs inherent in the critical variables in the medium-term planning process, developing a viable production plan that maximizes contribution to company profits. An illustration of the model is also provided, its application to the productive process of a Brazilian mechanical manufacturer.

This paper offers four contributions to the literature. First, it introduces a practical tool that has been developed with the specific intention of narrowing the gap that sometimes exists between long-term company goals and shop-floor scheduling short-term objectives. Second, it describes a mathematical optimization model in which the objective is to maximize contribution to profits rather than minimizing costs and therefore is not only more closely aligned with overall company objectives, but also more helpful for inter-functional coordination. Third, it develops a framework for analyzing different product/client pairs and describes how this input can be helpful for the strategic planning process. Lastly, it provides an illustration of the methodology by applying it to the case of an OEM supplier in Brazil.

This section introduces the paper. Section 2 describes production planning and control systems within the context a brief literature review. The third section describes the optimization model and presents the mathematical formulation. Section 4 presents an illustrative example and discusses results focusing specifically on the customer and product mix identified by the model. Section 5 concludes.

2. Problem positioning and literature review

This section provides an overview of the various stages of production planning and control systems and positions the methodology described herein within the academic literature examining connections with other planning levels as well as linkages with other functional areas of the firm.

2.1. Strategic direction and production planning and control systems

Production planning and control systems are responsible for materials flow planning and control through manufacturing processes and are tools to support strategic planning at both the tactical and the operational levels. Strategic planning identifies long term company goals through the definition of the main business drivers throughout a time horizon of five to ten years, depending on specific sector characteristics. The production planning and control system is deployed in tactical and operational planning, for the medium and short term. Medium term planning, or S&OP, covers the 6 to 24 month time horizon at the tactical level and helps translate strategic objectives into operational directives while also helping provide linkages among different functional areas of the firm, such as engineering, manufacturing, marketing, and sales planning.

The strategic importance of manufacturing has been extolled in the academic literature for decades as exemplified by Skinner (1985), Hayes, Wheelwright and Clark (1988), Hayes and Pisano (1996), and more recently by Hayes, Pisano, Upton and Wheelwright (2004). Ganesi (1998) identified managerial benefits in the broader application of S&OP, such as inter-departmental integration, multi-timeframe decision consistency, and the elimination of intra-organizational barriers. Olhager and Rudberg (2002) examined the role of manufacturing planning control systems in supporting the firm's marketing and manufacturing strategies, and focused on the importance of process-specific elements. S&OP can be helpful in mitigating the Bullwhip Effect, a solution for which was proposed by Warburton (2004). Other instances in which the advantage of S&OP integration with other levels of planning are of note are the case of uniform guaranteed lead time as investigated by Rao, Swaminthan, and Zhang (2005), and the case of manufacturing flexibility strategies as developed by Ketokivi (2006). Grimson and Pyke (2007) offered a five-stage framework for helping improve the effectiveness of S&OP processes with close linkages to overall company strategy. Olhager and Selldin (2007) used a survey-based design to analyze the interrelationships between manufacturing planning and control approaches at different levels and operational performance given market requirements.

According to Wallace (1999), S&OP focuses on aggregate volumes and product families. Issues related to product mix, to individual products, and to client orders are resolved at the more detailed operational level. The S&OP process provides the mid-term aggregate operations, sales, and inventory plans, which include both volume and value data. When it includes reliable financial data such as, for example, products' prices and costs, leading to marginal contribution to profits, the S&OP can act as a tool to substantially improve company results. These plans must also consider relevant constraints in the operations system in order to ensure that the plan is feasible at the operational level. There are various categories of constraints to be considered,

including manufacturing bottlenecks, workforce constraints, and supply chain characteristics, among others. Figure 1 summarizes the different levels of a production planning and control system and presents the planning process at the tactical and operational levels.

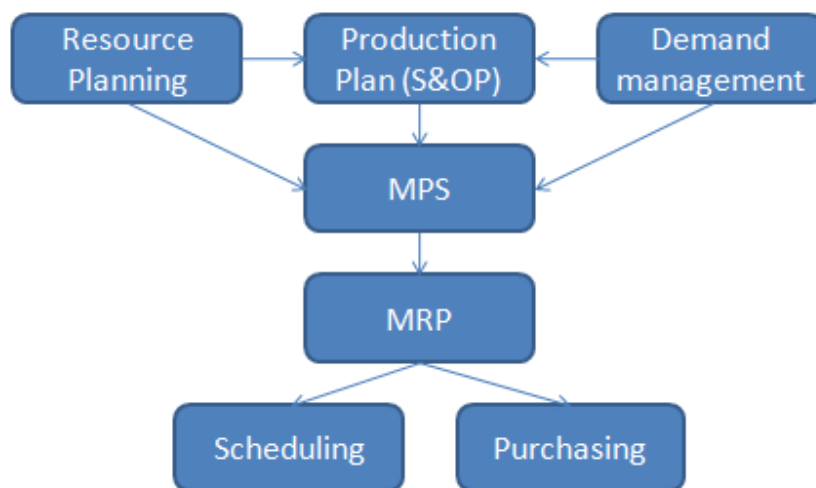


Figure 1 – Production planning and control system (adapted from Vollmann *et al.*, 1997).

The S&OP process provides input for the Master Production Schedule (MPS), i.e., short term planning. In this step, the plan is disaggregated from the broad product family level to the level of each specific SKU. Material Requirements Planning (MRP) also belongs to the short term planning phase as it generates the raw materials and component purchase plans. The last step of the Production Planning and Control System is execution (actual production). At this moment, production scheduling is generated and production and purchase orders are issued to the shop floor and to the suppliers.

2.2. Hierarchical production planning

The aggregate production plan is executed at the tactical level in a hierarchical planning model - in the flow proposed in Figure 1, the aggregate production plan fits within Sales and

Operations Planning. According to Axsater (1986), the purpose of the aggregate plan is to ensure that long-term considerations are not ignored when making short-term decisions. Singhal and Singhal (2007) examined the impact of early work in aggregate production planning on the recent evolution of operations and supply chain management. They considered a broader objective for aggregate production planning as it plays a key role in enterprise resource planning and organizational integration by linking operations with accounting, distribution, finance, human resources management, and marketing. According to Lee and Khumawala (1974), aggregate production planning is related to how the organization will respond to fluctuating demands on its productive system and also how it will determine aggregate production levels, inventory, and work force size. Giansi (1998) pointed out the impact of the planning process on direct and indirect costs, such as labor and inventory costs, on delivery speed, on delivery reliability, and on flexibility.

The concept of hierarchical production planning was first developed by Hax and Meal (1975), who proposed three aggregation levels: a) items - the lowest aggregation level corresponding to end products delivered to the customers; b) families - groups of items pertaining to a same product type and sharing similar setups; c) product types - groups of families having similar cost structures, manufacturing processes and seasonalities. The top decision level in a hierarchical production planning process focuses on product type decisions. At this level, product mix, inventories, and manufacturing strategies as well as hiring and layoff decisions are reached in each planning period. The product type planning is disaggregated to the family level and further disaggregated to the item level. From an analytical standpoint, each hierarchical level is constrained by the volume of the level immediately above it so short-term plan feasibility is not jeopardized.

Dempster *et al.* (1981) suggested two fundamental reasons for using a hierarchical approach: a) to reduce complexity, because aggregating products in families and product type groups simplifies planning; and b) to better cope with uncertainty, because the implicit hierarchy of decisions facilitates aggregate planning. Medium-term decisions, such as hiring and layoffs, can be taken based on an aggregate plan while more focused decisions can be postponed. They also point out that hierarchical planning has a parallel with the organizational structure of most firms.

2.3. Optimization models

The first optimization approach for aggregate production planning was developed by Holt, Modigliani and Simon (1956). The authors formulated the problem of defining the aggregate production rate and workforce size in each planning period so demand variations were absorbed and total costs were minimized. Three basic variables were developed to solve the problem: a) the size of the work force by hiring and firing in each period; b) the production rate with a constant work force level; c) the inventory and backlog level with a constant work force and a constant production rate. Since then there has been a vast body of literature on the topic – a summary of the relevant techniques can be found in Sprague *et al.* (1990).

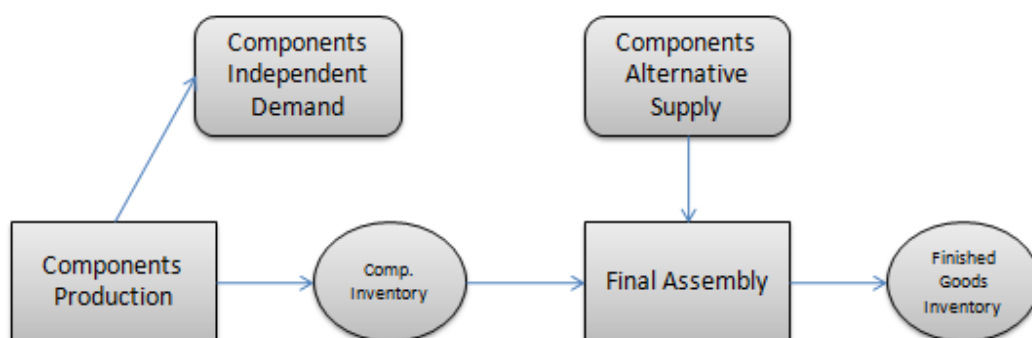


Figure 2 – Two-stage production flow (adapted from Bitran *et al.*, 1982).

Two publications by Bitran, Haas and Hax (1981, 1982) proposed linear programming models to solve the aggregate production planning problem respectively with a single stage and a two-stage approach at the product type aggregation level. The single stage model formulated the production plan per product type without consideration for pre-assembly component production. The objective was to minimize overall costs, including raw materials costs and inventory costs. The two-stage model differed from this one by assuming the existence of a process to produce components to be used in final assembly. They used two aggregation levels for components: items, i.e., components that are either necessary for assembly of a final product or have independent demand; and item types, i.e., groups of items with similar production costs, unit inventory costs and productivity. Figure 2 shows the production flow in a two-stage system.

The vast majority of the production planning optimization models in the literature is cost minimizing, and therefore do not take into account market considerations such as pricing, product mix, and contribution to profit margins. Özdamar *et al.* (1998) presented a formulation including subcontracting production capacity, existence of backorders, existence of maximum resource sub-utilization levels, and use of inventory and backorder goals per period. Newman and Kuchta (2004) formulated a mixed integer program to schedule iron ore production over multiple time periods in which the objective function minimizes deviations from planned production quantities.

Vaccaro *et al.* (2006) suggested a multi-criteria approach whereby an optimal result should include several considerations, such as: a) alignment with the market and company guidelines; b) physical constraints, such as resource capacity levels, product quality levels, and raw material availability; c) earnings maximization, expressed through financials; and d) inventory value minimization. These authors also pointed out several benefits to utilizing hierarchical planning with an optimization model, such as an increase in contribution margins,

better raw materials inventory control, improved inventory balance in all categories (raw materials, work-in-progress, and finished goods), and increased organizational learning. Feng, D'Amours and Bouregard (2008) presented an S&OP modeling approach that integrates cross-functional planning of sales, production, distribution, and procurement, allowing for the central evaluation of its impact before implementation.

3. Model and mathematical formulation

The methodology presented herein is robust and can be applied to most any manufacturing environment with adaptations. The objective is to identify the product/client mix that maximizes contribution to company profits. An effective costing system, good demand forecasting, efficient linkages with other functional areas, and coordination with the long-term plan and the short-term production schedule are essential prerequisites for obtaining maximum benefit from this medium-term strategic analytical tool. The formulation below applies to the particular situation in which clients agree to prices in advance as a function of volume, product characteristics, and other supply chain considerations – the same product can be sold to different clients at different prices depending on the characteristics of each contract. Because prices are agreed to in advance, individual product contributions to profit are known. In these circumstances identifying the optimal product/client mix has high strategic importance to the company because it offers subsidies for other areas of the firm, such as the sales force, for example, to act in a profit maximizing and not in a revenue maximizing way. The model's usage follows a sliding window approach, i.e., it is run on every analysis period with data from several (e.g., six to twelve) periods ahead. This section defines the variables used by the optimization model and presents the mathematical formulation.

3.1 Decision variables and parameters

3.1.1. Model indexes

The indexes used in the model are the following:

t – time unit (e.g., week or month);

p – product grouping (at the appropriate planning aggregation level);

c – component used in the assembly of the product grouping;

m – assembly line;

i – clients purchasing a product.

3.1.2. Model parameters

The model uses several parameters:

$drm_{m,t}$ = regular hours available in assembly line m in period t ;

$dhem_{m,t}$ = overtime hours available in assembly line m in period t ;

$drc_{c,t}$ = regular hours available to produce component c in period t ;

$dhec_{c,t}$ = overtime hours available to produce component c in period t ;

$vm_{m,t}$ = hourly production in assembly line m in period t ;

$vc_{c,t}$ = hourly component production in component cell c in period t ;

$dispex_{c,t}$ = availability to buy component c from a supplier in period t .

Overtime costs parameters are payroll variable costs and physical resource utilization:

$chem_{m,t}$ = overtime cost in assembly line m in period t ;

$chec_{c,t}$ = overtime cost to produce component c in period t ;

$chec_{c,t}$ = cost to source component c from an external supplier in period t (this cost may be set artificially high to indicate non-tangible additional costs other than purchase price such as, as for example, the extra effort to develop supplier relationships, and the disruption resulting from obtaining additional sourcing alternatives).

The inventory holding cost is a function of the inventory holding discount rate (a function of the company's cost of capital).

$ce_{p,t}$ = cost of a product p in period t ;

r = discount rate used to calculate the inventory holding cost;

$mu_{i,p,t}$ = unit contribution margin of product p , at client i 's price in period t ;

$d_{i,p,t}$ = demand for product p , by client i , in period t .

The following parameters are meant to ensure feasibility of the production plan, that is, they ensure that there will be available resources to produce the products listed in the plan.

$pm_{p,m}$ = binary parameter linking product p with assembly line m : if it is possible to assemble the product, $pm_{p,m} = 1$, otherwise $pm_{p,m} = 0$;

$pc_{p,c}$ = quantity of component c assembled in product p ;

ei_p = initial stock volume of product p , in units.

3.1.3. Decision variables

$Xrm_{p,m,t}$ = regular production of product p , in assembly line m , in period t ;

$Xhem_{p,m,t}$ = overtime production of product p , in assembly line m , in period t ;

$Xrc_{p,c,t}$ = regular production of component c assembled in product p , in period t ;

$Xhec_{p,c,t}$ = overtime production of component c assembled in product p , in period t ;

$Xexc_{p,c,t}$ = quantity of outsourced component c assembled in product p , in period t ;

$E_{p,t}$ = units of product p in inventory at the end of a period t ;

$V_{i,p,t}$ = sales volume of product p , to client i , in period t .

All production variables are integer.

3.2. Objective function

The objective function Z to be maximized is the marginal contribution to the profit of the company by adding the unit contribution margins of products forecasted to be sold and subtracting additional product and component overtime production costs and inventory holding costs.

$$Z = \sum_{i=1}^I \sum_{t=1}^T \sum_{p=1}^P \left[mu_{i,p,t} V_{i,p,t} - ce_{p,t} r E_{p,t} - \sum_{m=1}^M (chem_{m,t} Xhem_{p,m,t}) - \sum_{c=1}^C (chec_{c,t} Xhec_{c,t} - cexc_{c,t} Xexc_{c,t}) \right]$$

3.3. Constraints

3.3.1. Inventory conservation equation

The inventory conservation equation calculates the inventory of product p at the end of period t , considering the inventory at the end of the previous period (period $t-1$) and the production and sales in period t .

if $t > 1$,

$$E_{p,t} = E_{p,t-1} + \sum_{m=1}^M ((Xrm_{p,m,t} + Xhem_{p,m,t}) * pm_{p,m}) - \sum_{i=1}^I V_{i,p,t}, \quad \forall p = 1, \dots, P, \forall t = 2, \dots, T$$

if $t = 1$,

$$E_{p,t} = Ei_p + \sum_{m=1}^M ((Xrm_{p,m,t} + Xhem_{p,m,t}) * pm_{p,m}) - \sum_{i=1}^I V_{i,p,t}, \quad \forall p = 1, \dots, P$$

3.3.2. Assembly line capacity constraints

Assembly line capacity constraints ensure that allocated volumes in each assembly line m and in each cell producing a given component c conform to production availability in any given period t .

$$\sum_{p=1}^P (Xrm_{p,m,t} pm_{p,m}) = dr_{m,t} vm_{m,t}, \quad \forall m = 1, \dots, M, \forall t = 1, \dots, T$$

$$\sum_{p=1}^P (Xhem_{p,m,t} pm_{p,m}) \leq dhem_{m,t} vm_{m,t}, \quad \forall m = 1, \dots, M, \forall t = 1, \dots, T$$

3.3.3. Component production constraints

Those constraints ensure that production of a given product p in period t is limited to the available capacity to produce each component c in product p 's configuration.

$$\sum_{p=1}^P (Xrc_{p,c,t} pc_{p,c}) \leq drc_{c,t} vc_{c,t}, \quad \forall c = 1, \dots, C, \forall t = 1, \dots, T$$

$$\sum_{p=1}^P Xhec_{c,t} pc_{p,c} \leq dhec_{c,t} vc_{c,t}, \quad \forall c = 1, \dots, C, \forall t = 1, \dots, T$$

$$\sum_{p=1}^P Xexc_{c,t} pc_{p,c} \leq dispex_{c,t}, \quad \forall c = 1, \dots, C, \forall t = 1, \dots, T$$

$$\sum_{m=1}^M [(Xrm_{p,m,t} + Xhem_{p,m,t}) pm_{p,m}] pc_{p,c} = Xrc_{c,t} + Xhec_{c,t} + Xexc_{c,t}, \quad \forall p = 1, \dots, P, \forall c = 1, \dots, C, \forall t = 1, \dots, T$$

3.3.4. Maximum demand constraint

This equation ensures that the sales of a given product p is limited by the respective forecasted demand in each period t .

$$V_{i,p,t} \leq d_{i,p,t}, \quad \forall i = 1, \dots, I, \forall p = 1, \dots, P, \forall t = 1, \dots, T$$

3.3.4. Non-negativity constraints

$Xrm_{p,m,t}$, $Xhem_{p,m,t}$, $Xhec_{c,t}$, $Xhec_{c,t}$, $Xrc_{c,t}$, $E_{p,t}$ and $V_{p,t}$ must be equal or higher than zero.

4. Illustrative application

The optimization model was used in a specific application in a Brazilian multinational company of the metal-mechanic segment producing durable goods that are supplied to large OEMs. The company has a medium- and short-term planning structure very similar to that

presented in Figure 1. At the tactical level, an S&OP process updates 18-month sales forecasts every month. An integrated sales, production, and inventory plan results from this process.

4.1 Production process description

The production aggregation structure of the company has four levels. The highest level is the product family, with products of similar application and technical characteristics. The next level is the subfamily, in which the products are grouped in an application range with higher degrees of specificity. The third level, the model level, is characterized by products with similar physical structures and manufacturing processes. The last level is the SKU. At this level, the product has its final configuration, such as its pallet type and accessories. The company product portfolio is composed of 7 families, divided in 40 subfamilies, 250 models and 1,500 SKUs.

In the company's product hierarchy, the SKU would be equivalent to Hax and Meal's (1975) item level. The model in the company's hierarchy would be equivalent to the family level in Hax and Meal (1975), since they have similar product structures and similar setups. Their product type level is equivalent in the company's subfamily, for which productive processes, cost structure, and production seasonalities are similar. The company's family level has a broader scope, including some similarities in cost and productive processes. The S&OP production plan is developed at the model level and consolidated at the subfamily and family levels. The model level was chosen due to 2 main reasons. First, manufacturing constraints would be impossible to include for aggregation above the model level. Second, there is very good precision in the contribution margin and variable cost determination at the model level.

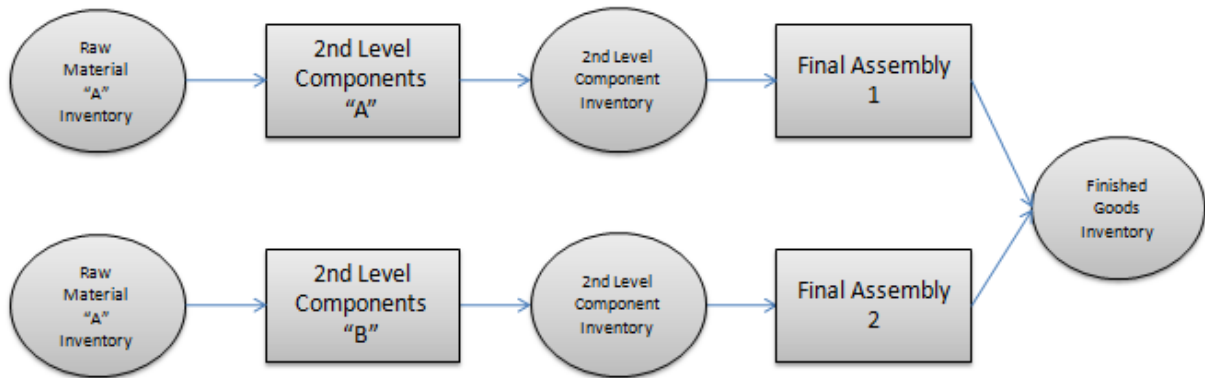


Figure 3 – Manufacturing flow.

The manufacturing structure of the company is organized in cells, each of which can supply components to several cells. Figure 3 presents a simplified process flow. Raw materials are used to manufacture 2nd level components and these components are then manufactured into 1st level components to be used in final assembly. 1st level components can't be stocked due to technical constraints, so their production plan must follow the final assembly production plan.

The company has eight final assembly lines and three 1st level component cells, all of which are considered critical. The assembly lines have some differences since each one of them is configured to assemble a certain group of products. The component cells work with the same logic, as each one produces a certain group of components.

Client	Model	Contribution Margin	Sales Plan	Month
Client A	A20TRW	20.25	3,000	T1
Client A	A35TRW	25.12	3,500	T1
Client B	A20TRW	17.14	15,000	T1
...	...	...	...	...

Table 1 – Sales forecast example.

The sales forecast is formed with statistical tools, specific information obtained from the market and provided by clients, and additional input from the sales force. The aggregation level used is models per client. Clients are specified because of differences in the absolute contribution margins for similar models sold to different clients. Table 1 shows a portion of a sales forecast.

In the sample company, the production plan is projected for a six month time horizon, considering forecasted sales per client per model. The constraints used in the model formulation are: regular and overtime production capacities per assembly line and per first level component cell, the component needs for each model, and maximum demand per model in each period.

The financial criteria used by the company and in the model are to maximize the unit contribution margin, that is, the unit price minus the unit variable cost. The contribution margins used in the linear programming model were taken from the average sales price and the average variable costs for the previous 3 months. The other financial parameters are those variable costs having an additional negative impact on earnings such as overtime production costs and inventory holding costs. Overtime production impacts margins negatively by imposing an additional variable cost. Although the inventory holding costs do not have a direct impact over contribution margins, they are included because inventory holding costs negatively affect the company's cash flow.

4.2. Data collection

The data for the application consists of demand projections per model and per client, regular and overtime capacity available, productivity of each assembly and component line, the company's inventory holding discount rate, the contribution margin per client/model, and costs per model. The time horizon for the application was six months. Table 2 presents the aggregate capacity of the assembly lines for the period.

	T1	T2	T3	T4	T5	T6
Capacity	1,435,512	1,424,384	1,343,706	1,538,446	1,395,173	1,100,381

Table 2 – Total production capacity

Table 3 presents production capacity for each component cell.

	T1	T2	T3	T4	T5	T6
C1	508,260	504,320	475,755	544,705	493,978	389,568
C2	193,500	192,000	181,125	207,375	188,063	148,313
C3	129,000	128,000	120,750	138,250	125,375	98,875

Table 3 – Component capacity production.

Table 4 presents the unconstrained sales demand for the six-month period.

	T1	T2	T3	T4	T5	T6
Demand	1,939,497	1,793,133	2,169,236	1,906,292	1,856,453	2,067,365

Table 4 – Unconstrained sales demand.

The initial inventory volume in period T0 was 764.824 units. The average contribution margin, weighted by the average volume of the unconstrained sales demand, was R\$13.67 (the Brazilian Real exchange rate was one US dollar for R\$ 2.40 on February 24th 2009 - financial data in this paper is reported for illustrative purposes only and does not represent the actual values.)

4.3. Results and discussion

Utilization of the model directly impacted company results. Operational profit, return on assets, and cash flow generation improved substantially as products with a higher contribution margin were prioritized and the lowest cost products were held in inventory. The average product/client combination margin weighted by confirmed volume obtained by the model was R\$17.22, (constrained demand). This represented an improvement of 26% relative to fulfillment of all unconstrained demand. The average margin of the products/client combination whose demand was not fulfilled by the optimization model was R\$6.35. Table 5 summarizes the

contribution margins obtained for fulfilled demand by the model, for unfulfilled demand by the model, and for unconstrained demand.

Unconstrained demand	13.67
Products/clients confirmed by the optimization model	17.22
Products/clients not confirmed by the optimization model	6.35

Table 5 – weighted average margin for product/client combinations

In this illustrative example, the model results do not suggest overtime use because of the low average margins of the unfulfilled product/clients even though the average margin of the products assembled in line L4, geared towards top-of-line models, was R\$17.66, higher than the average value of all the confirmed products/clients. An improvement in this assembly line's capacity would improve the average margin of the company. Resulting sales, production, and inventories are reported in Table 6:

	T0	T1	T2	T3	T4	T5	T6
Unconstrained Demand		1,939,497	1,793,133	2,169,236	1,906,292	1,856,453	2,067,365
Non-confirmed demand		633,844	759,517	764,228	564,518	428,643	683,099
Sales		1,305,653	1,033,616	1,405,008	1,341,774	1,427,810	1,384,266
Production		1,435,512	1,424,384	1,343,706	1,538,446	1,395,173	1,100,281
Inventory	764,824	894,683	1,285,451	1,226,931	1,423,603	1,390,966	1,106,981

Table 6 – Results

There is an increase in inventory when compared to initial levels indicating the existence of an initial mix of products in inventory without corresponding demand. It also indicates an imbalance between the individual model production capacity and demand. Considering that regular capacity must be utilized, if a specific assembly line's models don't have enough demand in the period, the optimization model will suggest production of models with lower impact on cash flow. Only the cell that produces the component C2 has its entire capacity utilized, resulting in a lack of this specific component in the assembly line. However, due to the low margins of the

products that use this component, an average of R\$6.28, any investment in increasing capacity of this resource would increase the capacity of the company to produce models with lower contribution margins than the current average margin.

Use of the optimization model also shed light on the company's operational performance indicators, especially those related to the delivery of goods. Delivery reliability increased as the model took into account all system constraints. The optimization model also brought intangible benefits to the management of client/product mix. Figure 4 presents a matrix which correlates the average contribution margin and the sales volume per client/product pairing, herein called SKU, during the analysis period.

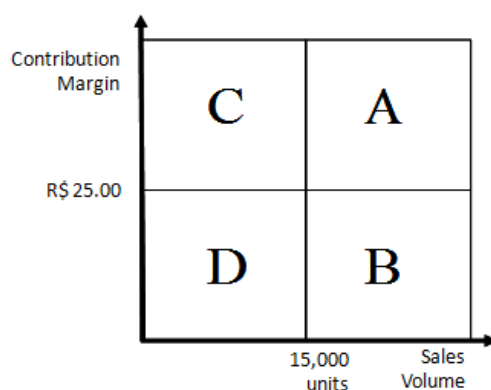


Figure 4 – Contribution margin and sales volume

Quadrant “A” represents SKUs with volumes above 15,000 units and a contribution margin higher than R\$25.00 during the period of analysis. Quadrant “B” represents SKUs with volume above 15,000 units and contribution margin under R\$25.00. Quadrant “C” represents SKUs with margins above R\$25.00 and volumes under 15,000 units. Quadrant “D” represents SKUs with margins and the volumes under those limits. Table 7 presents a hypothetical situation in which all unconstrained demand is fulfilled and classified in one of the four categories described above.

Classification	SKUs Nr.	% SKUs	Ponderate average margin	Average earning by SKU	Total earnings	% Earning
A	23	4%	31.55	1,368,153.55	31,467,531.64	20%
B	127	20%	11.00	801,660.28	101,810,856.02	63%
C	194	31%	31.36	60,148.09	11,668,728.96	7%
D	286	45%	13.82	53,851.41	15,401,502.30	10%

Table 7 – Classification of the SKUs for the unconstrained demand

24% of the SKUs classified as “A” and “B” account for 83% of company earnings. Although the average margins weighted by volumes for class “B” are lower, aggregate earnings are much higher than those of classes “C” and “D” due to much higher volumes. The choice to prioritize class “B” class over class “C”, which has higher unit margins, leads to higher total earnings and reduction of operational complexity due to fewer clients and products. The lower complexity levels reduce logistics costs as well as client and product portfolio management costs. As an alternative strategy, there could be a sales and marketing effort to increase volumes of class “C” items, leading to an increase in total company earnings. This discussion is an example of the strategic impact of an informative S&OP process on other functional areas in the firm and illustrates the power of this integrated methodology.

In this illustration 77 SKUs were not produced at all, 45 of which were in quadrant “D”, and 32 of which were in quadrant “B” - the methodology prioritized “C” SKUs over “B” SKUs because the main optimization criterion was contribution to profits. 30 SKUs have their demand only partially fulfilled, 4 of which were class “B” and 26 of which were class “D”. The very existence of production selections for class “B” and class “D” SKUs in this illustration is a result of the desirability to fully utilize manufacturing, i.e., if there is not sufficient demand to fully use assembly lines with other product models, SKUs with lowest contribution margins will also be assembled. Table 8 presents the classification by sales volume/contribution margin of the SKUs selected in the illustration. In this case, 21% of SKUs are responsible for 82% of earnings.

Classification	SKUs Nr.	% SKUs	Ponderate average margin	Average earning by SKU	Total earnings	% Earning
A	23	4%	31.55	1,368,171.96	31,467,955.11	23%
B	95	17%	14.15	842,875.50	80,073,267.61	59%
C	194	35%	32.06	60,180.18	11,674,954.04	9%
D	241	44%	14.58	53,072.37	12,790,440.65	9%

Table 8 – Classification of SKUs in the illustration

The weighted average margin increased in classes “B”, “C” and “D” with the selection of the respective methodology SKUs. For example, in class “B”, the margin went from R\$11.00 to R\$14.15, an increase of 29%. Again, this finding can be used to support the company’s marketing strategy. For example, from the analysis of the results, several marketing suggestions and analyses are possible, such as verifying the appropriateness of increasing volume of “C” items, of increasing prices of “B” items, and examining the possibility of migrating “D” items to other quadrants or, absent other strategic reasons to produce them, to have them discontinued. This kind of analysis must be made focusing on strategic determinants that are not included in the quantitative analysis, such as the importance of the clients and the development of new markets.

Turning to individual client and product model analysis, 4 of the 74 clients were not serviced, i.e., no products were assembled for them. 12 of the 74 clients, or 16 % of the total client portfolio had less than 25% of their demand serviced. On the product side, 2 product models were not produced 37 had less than 25% of their demand produced. The elimination of these products would represent an 18% reduction in the product portfolio.

5. Conclusion

The use of the methodology presented herein gives complete visibility of the client/product combinations that offer highest return in each tactical planning cycle, given market demand and operational constraints. This is a powerful tool to help the marketing and sales

functions. The results of the optimization model can provide support for marketing strategies, directing efforts to prioritize more profitable clients and products and to reduce focus on less profitable client/product combinations.

The model can also be useful for product development, as it identifies better margin products and production lines with higher demand products. The lines which produce the products with the lowest demands or margins could absorb new products and thus improve the company's sales mix. Furthermore, this methodology can identify the manufacturing resources that constrain sales of products to clients whose profitability contribute positively to the results of the company.

The results led to the rationalization of the product/client mix, with increased focus on the most attractive opportunities. Sales and operations planning processes are also simplified with this mix rationalization. As a simulation tool, the optimization model allows the use of different configurations, for example, different productivity and capacity scenarios. Simulations can be used for new product feasibility analysis by testing volumes and margins in production planning and taking into account the relevant manufacturing constraints. The utilization of a structured process with well defined rules ensures control over improvement needs, systematizes analytical decision processes, and increases the company's understanding of the planning process.

As stated in the introduction, this paper offers four main contributions to the literature. The first is to offer a tool that not only helps integrate different functional areas of the firm, but also helps bridge long-term strategic objectives with short-term shop-floor requirements. The second is to use pricing as well as costing information to obtain individual product contributions to profit and use it (as opposed to product costs) as a decision variable, resulting in a methodology that is more closely aligned with overall company objectives. The third contribution is the development of a conceptual framework to analyze different product/client pairs and

identify those that are most and least profitable. Finally, the paper illustrates the methodology introduced herein with the case of an OEM supplier in Brazil.

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