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A Practical Framework for Aggregate Production Planning

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ABSTRACT

Aggregate planning (AP) is widely used in industry to determine production levels given the forecasted demand for a family of products over a finite planning horizon. Here, we extend a spreadsheet-based AP approach to include both marketing and financial aspects. Previous authors have suggested a "linked spreadsheet" approach where the results of an earlier module are fed into a subsequent module. That is, it begins with a sales forecasting module to determine demand, then an aggregate planning module is used to compute production levels, and, finally, a cash budgeting module is used to evaluate the amounts of required cash. While this spreadsheet approach is commendable due to its practicality, unfortunately it is clear that it would give rise to suboptimal solutions due to its sequential nature. Here we extend this spreadsheet approach by developing an integrated model that incorporates both marketing and financial aspects into the traditional, operations-oriented aggregate planning methodology. On the marketing side, we determine optimal product prices and (the resulting) demand in each period, whereas on the financial side we include monthly sales collections, loan interest, fixed costs, and a minimum allowable cash balance in determining optimal production, workforce, and inventory levels. We incorporate cashflow accounting to ensure financial viability of the proposed plan.

Keywords: *accrual accounting, aggregate production planning, cash flow accounting, linear programming, marketing-finance-operations interface*

1. INTRODUCTION

The aggregate planning of production in operations management (OM) generates a medium-term plan by determining, for each planning period, the production quantity, inventory level, workforce size and any associated hires/layoffs, overtime hours worked, direct materials needed, and quantity (if any) to be subcontracted, see e.g., Rasmi and Turkay (2021), Cheraghalikhani *et al.* (2019), Luo *et al.* (2023), or Pereira *et al.* (2020) for recent surveys of this topic. While a great deal of the traditional OM literature discusses different approaches to aggregate planning, very little research addresses practical cash flow considerations that industry professionals must account for in a realistic aggregate plan. Indeed, while scholarly research recognizes the value of collaboration among different functional areas of a business (aggregate planning is now more commonly known as Sales and Operations Planning, or S&OP, and the impact of S&OP on firm performance is investigated in Chatzoudes and Chatzoglou (2011) and Thomé *et al.*, (2012)), the treatments of the aggregate planning topic in OM textbooks do not reflect this (see e.g., Collier and Evans (2024), Heizer *et al.* (2023), Jacobs and Chase (2021), Krajewski and Malhotra (2022), and Stevenson and Kull (2024)).

A critical issue with attempting to integrate the production planning process across multiple business functions is the so-called "silo mentality" which has been studied by several researchers in the past, see e.g., Jeske and Olson (2025) or Schonberger (2020). A key reason for the silo effect may be attributed to the fact that different functions may have different, often conflicting, objectives: for example, Operations might be concerned about excessive changeovers, preferring a smoother production schedule; Marketing may like to have ample inventory to avoid any lost sales; and, Finance may wish for lower inventory levels in order to meet working capital constraints (Montague, 2017). S&OP has been suggested as an effective approach to strike a compromise between these misaligned goals (Shah *et al.*, 2025). Msimangira and Venkatraman (2014), using an online discussion forum with supply chain practitioners in New Zealand as participants, conclude that integrating both inter- and intra-organizational processes in a holistic manner is critical to eliminating silos. Selmi *et al.* (2021) explore, using a case study of five top French multinational corporations, the extent to which financial planning concerns such as working capital requirements is integrated into the S&OP process. Montague (2017) discusses the five stages of maturity of an organization's S&OP process, namely, react, anticipate, integrate, collaborate, and orchestrate. Regardless of the level of maturity of the S&OP, cross-functional collaboration is minimally necessary to yield a "one number plan" i.e., all functions agreeing on a consensus plan for moving forward instead of each working with a different set of numbers. The challenges of measuring S&OP performance is addressed in Hulthén *et al.* (2017) using metrics of effectiveness and efficiency at different S&OP maturity levels.

Developing an aggregate plan without considering marketing goals or financial constraints may well result in an unrealistic solution. Buxey (2003) discusses the "worrying gap … between aggregate planning theory and industrial practice" and concludes that the theory does not address all the factors that managers must take into account. This gap between literature and practice in aggregate planning is also discussed in daSilva *et al.* (2006). Their paper aims to bridge this gap between theory and practice by developing a user-friendly decision support system that hides the complexity of the underlying multiple criteria, mixed-integer linear programming model. Moreover, in past work, Chien and Cunningham (2000) have demonstrated a "linked spreadsheet" approach to model aggregate production levels which are then connected to a financial plan. However, their approach is sequential with the results of one module feeding to another. They do not attempt to solve the problem optimally, nor do they incorporate a marketing promotion with the possibility of influencing demand. (Instead, they use time-series forecasting to determine future demands.) Here, we modify their approach to simultaneously consider the constraints and goals of operations, marketing, and finance within a monolithic optimization framework. The resulting linear program can be solved optimally using commonly available spreadsheet software, thereby demonstrating the managerial applicability of the approach. With regard to the influence of pricing on demand, we use the linearization of the demand function proposed in Lusa *et al.* (2012). On the financial side, we incorporate cash flow accounting to ensure that financial constraints are met.

In traditional aggregate planning, the two approaches commonly employed are the chase and level strategies. In the chase strategy, little or no inventory is held, and the workforce level is adjusted in each period to correspond to the expected demand. On the other hand, in the level strategy the workforce size and production level are held stable with inventory and/or backlogging being utilized to buffer any supply-demand mismatch. In contrast to these heuristic approaches, one can derive an optimal, i.e., a minimum-cost production plan by building a linear programming model. Costs typically considered in such a model are regular-time wages, overtime wages, subcontracting costs, material costs, hiring and layoff costs, inventory carrying costs, and backlogging costs. We extend this optimization approach to include the option of influencing demand through price promotions in the presence of practical limitations on cash availability.

Determining an aggregate production plan in isolation, without considering the marketing function's plan for pricing promotions could well lead to suboptimal solutions (see e.g., Chopra (2019)). The timing and extent of price discounts will influence not only the magnitude of demand, but its variability from one period to the next which, in turn, has an adverse impact on the total cost of the aggregate plan. Without explicit consideration of price promotions, scenarios such as backorders and lost sales, as well as excessive levels of inventory and overtime will be more likely. Hence collaboration with the marketing department to determine the timing and extent of promotions should be done simultaneously with the derivation of production quantities and workforce levels.

When cash requirements and availability are not taken into consideration, a proposed production plan - although optimal for the traditional constraints of aggregate planning - may not even be feasible due to financial limitations faced by the firm. For example, the firm may not be able to fund the purchase of the materials needed to manufacture the quantity specified in the aggregate plan in one or more periods. By incorporating a minimum mandatory cash balance along with a borrowing limit, the aggregate plan will generate a solution that does not violate the financial constraints that the firm might be facing. By simultaneously considering marketing plans, financial constraints, and operational requirements in our model, we aim to develop an optimization model that is more realistic for industry. It is our hope that managers find this methodology approachable and easily applied in practice.

The rest of this paper is organized as follows: Section 2 reviews literature in aggregate planning that focuses on the incorporation of marketing and finance considerations. In Section 3 we review the traditional linear programming model for aggregate planning, followed by extensions to incorporate marketing and finance aspects in Sections 4 and 5 respectively. A numerical example and its optimal solution are presented in Section 6. We conclude the paper in Section 7 with a discussion of the limitations of our approach and possible future research directions.

2. LITERATURE REVIEW

Tuomikangas and Kaipia (2014) provide a thorough review of research in aggregate planning from the perspective of coordination. Buxey (2003) and daSilva *et al.* (2006) both discuss the gap between sophisticated models and practical applicability. Our paper attempts to bridge this gap by developing a spreadsheet-based optimization approach that incorporates both marketing and financial aspects into the traditional aggregate production planning methodology. In the following subsections, we discuss the extant literature where the aggregate planning process was enhanced by adding: (i) marketing considerations; (ii) finance considerations; and (iii) both marketing and finance considerations.

2.1 The marketing-operations interface

Researchers have pointed out the importance of considering marketing strategies when determining production schedules, e.g., Eliashberg and Steinberg (1987), or Hayashi *et al.* (2009). O'Leary-Kelly and Flores (2002) use an empirical model to quantify the value of adding marketing aspects into the production plan. They look at certain conditions (demand uncertainty and a firm's business strategy) under which integration should take place and discuss the advantages of such integration. Upasani and Uzsoy (2008) review literature that integrates the two aspects with a specific focus on lead times and production capacity. We refer the reader to Upasani and Uzsoy (2008), Smith *et al.* (2009), and Martinez-Costa *et al.* (2013) for extensive literature reviews on the interface between production and marketing decisions.

Still others consider marketing decisions and production decisions simultaneously through the modeling of pricing and promotions. For example, Ulusoy and Yazgac (1995) develop a multi-product, multi-period aggregate planning model that uses advertising and pricing as tools to smooth demand. Backlog is possible but outsourcing is not considered. Eliashberg and Steinberg (1987) present a model that considers seasonal demand. They look at the link between pricing policies and product delivery and inventory policies. They employ a Stackelberg model where the distributor maximizes his profit, and the manufacturer then follows by maximizing her own profit function. They make recommendations regarding appropriate inventory policies and channel prices. Finally, Sogomonian and Tang (1993) consider the level of promotion and the level of production simultaneously. Additionally, they evaluate the benefits of coordinating these decisions within a firm by comparing the results to a scenario where the two decisions are made separately. They use mixed-integer programming to maximize profits with the decision variables being the promotion and production levels. Through an illustrative example, they show that the net profit, when marketing and production are coordinated, is higher than when these decisions are made in isolation.

2.2 The finance-operations interface

Other researchers have addressed how financial concerns may be considered when making operational decisions (e.g., Gohareh *et al*. 2017, Hahn and Kuhn 2012). Merville and Tavis (1973) use mixed-integer programming to determine optimal cash flow, i.e., credit and borrowing decisions, along with optimal inventory levels. More recently, Dougherty and Gray (2013) discuss how aggregate planning can help align the financial and operational goals of a company. They discuss how aggregate planning and financial planning interact in terms of cash flow, budgets, and capital investment decisions. Pega Magro *et al*. (2000) call for an integration between production and finance when considering aggregate planning. They use linear programing to produce a budget for a Portuguese mining company and observe considerable savings when compared to the actual budget. Barbosa and Pimentel (2001) develop a linear programming model for cash flow management that is specific to the construction industry. However, there are some generalizations to cash flow management such as loans, expenses, and revenue. They use cash forecasts as input and optimize profits by manipulating cash transactions over the planning horizon.

Chien and Cunningham (2000) use a "linked spreadsheet" approach to model aggregate production levels that connect to the financial plan. They show that the interrelatedness between production planning and cash budgeting can be modeled and adapted to create an overall business plan. However, they do not attempt to solve the problem optimally. Our paper modifies their approach by formulating a linear program that optimizes pricing (marketing) as well as incorporating cash flow (finance). Finally, Sodhi and Tang (2009) incorporate cash flows and demand uncertainty into a linear programming model. They point out that most inventory models do not consider the risk of cash flows (i.e., acquiring raw materials when demand is high, or write-offs when demand is low). We follow a similar approach by including the interest paid on loans along with a minimum operating cash balance. The interested reader is referred to Sodhi and Tang (2009) for a detailed explanation of the importance of cash flows within the supply chain.

2.3 Integrated marketing, finance, and operations

While previous research in aggregate planning has looked at the relationship between two functional areas (either operations-marketing or operations-finance), few have simultaneously considered all three functional areas. To our knowledge the only papers in aggregate planning that consider all three functional areas are Damon and Schramm (1972), Chien and Cunningham (2000), and Lusa *et al*. (2012). The model presented here extends the spreadsheet approach of Chien and Cunningham (2000) by combining the price setting & demand determination, production planning, and cash budgeting functions within a monolithic optimization framework so that the proposed production quantities are not merely feasible, but also optimal.

3. MODEL I: TRADITIONAL AGGREGATE PLANNING (AP)

Consider a firm selling a single family of products and a planning horizon with multiple periods (t=1,2,⋯T). We begin by defining the following input parameters:

r	Regular-time wage rate (\$/hour)
v	Overtime wage rate (\$/hour)
c	Inventory carrying cost (\$/unit/period)
h	Hiring cost (\$/hire)
l	Layoff cost (\$/layoff)
m	Material cost (\$/unit)
N_t	Number of working days in period t (days)
LS	Length of regular-time shift (hours/day)
LC	Labor content of product (hours/unit)
PR	Regular-time daily production rate (units/worker/day)
OL	Overtime limit (percentage)

The regular-time daily production rate can be computed as: $PR=(LS/LC)$. The overtime limit is expressed as a percentage of regular-time output. D_t is the demand in period t. The objective is to minimize the aggregate plan cost over the planning horizon. The following decision variables are determined by the traditional AP model (we will assume backlogging is not permitted in order to simplify the formulation):

P_t	Number of units produced in regular time in period t (units)
O_t	Number of units produced in overtime in period t (units)
I_t	Ending inventory in period t (units)
H_t	Number of hires in period t (workers)
L_t	Number of layoffs in period t (workers)
W_t	Workforce size in period t (workers

The cost minimizing production quantities and associated variables can be determined by solving the following linear program:

$$Minimize\ r\ LS\sum_{t=1}^{T} N_t\, W_t + v\ LC\sum_{t=1}^{T} O_t + c\sum_{t=1}^{T} I_t + h\sum_{t=1}^{T} H_t + l\sum_{t=1}^{T} L_t + m\sum_{t=1}^{T}(P_t + O_t) \quad (1)$$

subject to:

$$I_{t-1} + P_t + O_t - D_t = I_t \qquad t = 1,2,\dots T \qquad (2)$$

$$W_{t-1} + H_t - L_t = W_t \qquad t = 1,2,\dots T \qquad (3)$$

$$P_t \le PR\ N_t\, W_t \qquad t = 1,2,\dots T \qquad (4)$$

$$O_t \le OL\ P_t \qquad t = 1,2,\dots T \qquad (5)$$

$$P_t, O_t, I_t, H_t, L_t, W_t \ge 0 \qquad t = 1,2,\dots T \qquad (6)$$

Eqn. (2) and Eqn. (3) ensure that all inventory and employees are accounted for, where I_o and W_0 represent the initial levels of inventory and workforce respectively. Frequently in these types of models, constraints may also be added to reflect desired levels of ending inventory (I_T) and ending workforce (W_T). Eqn. (4) imposes a capacity limit on each period based on the daily regular-time production rate and available labor hours in that period. Eqn. (5) reflects the maximum permitted production quantity during overtime in each period. Eqn. (6) reflects the non-negativity of the decision variables. In the next two sections, we discuss the incorporation of marketing and finance aspects into this traditional AP paradigm.

4. MODEL II: AGGREGATE PLANNING WITH MARKETING ASPECTS

The revenue function may be written as $R_t = D_t\, p_t$ where D_t is the demand in period *t* and p_t is the price in period *t.* We follow the approach of Lusa *et al*. (2012) to define and linearize the demand function, as follows:

$$D_t = \alpha - \beta(p_t)^{\gamma},$$

where: $\alpha, \beta > 0$; $\gamma \ge 0$

The corresponding revenue function is $R_t = D_t\, p_t = \alpha\, p_t - \beta(p_t)^{\gamma+1}$. Given a discrete set of admissible prices $\{n_k \mid k = 1, 2, \dots K\}$, binary variables y_{kt} $(k = 1, 2, \dots K; t = 1, 2, \dots T)$ are used to indicate the price to be chosen in each period: i.e.,

$$p_t = \sum_{k=1}^{K} n_k y_{kt}$$

where:

$$\sum_{k=1}^{K} y_{kt} = 1 \qquad t = 1, 2, \dots T$$

Note that y_{kt} is not a decision variable in the traditional aggregate planning model because price setting is not done by an operations manager but rather the marketing team. By collaborating with marketing, the aggregate plan can also select a price that is optimal given that price affects demand, and demand, in turn, affects the aggregate plan. Therefore, p_t , the selling price of the product in period t is also now a decision variable. Then the demand and revenue functions can be written as:

$$D_t = \alpha - \beta(p_t)^{\gamma} = \alpha - \beta\sum_{k=1}^{K}(n_k)^{\gamma} y_{kt} \qquad t = 1, 2, \dots T$$

$$R_t = \alpha\, p_t - \beta(p_t)^{\gamma+1} = \alpha\sum_{k=1}^{K} n_k y_{kt} - \beta\sum_{k=1}^{K}(n_k)^{\gamma+1} y_{kt} \qquad t = 1, 2, \dots T$$

The above four relationships are included in the model below as Eqns. (7) through (10). Note that the objective function, Eqn. (1'), now maximizes gross profit. Eqn. (11) stipulates the domain of the binary variables.

$$Maximize\ \sum_{t=1}^{T} R_t - \{r\ LS\sum_{t=1}^{T} N_t\, W_t + v\ LC\sum_{t=1}^{T} O_t + c\sum_{t=1}^{T} I_t + h\sum_{t=1}^{T} H_t + l\sum_{t=1}^{T} L_t + m\sum_{t=1}^{T}(P_t + O_t)\} \quad (1')$$

subject to:

$$I_{t-1} + P_t + O_t - D_t = I_t \qquad t = 1, 2, \dots T \qquad (2)$$

$$W_{t-1} + H_t - L_t = W_t \qquad t = 1, 2, \dots T \qquad (3)$$

$$P_t \le PR\ N_t\, W_t \qquad t = 1, 2, \dots T \qquad (4)$$

$$O_t \le OL\ P_t \qquad t = 1, 2, \dots T \qquad (5)$$

$$P_t, O_t, I_t, H_t, L_t, W_t \ge 0 \qquad t = 1, 2, \dots T \qquad (6)$$

$$p_t = \sum_{k=1}^{K} n_k\ y_{kt} \qquad t = 1, 2, \dots T \qquad (7)$$

$$\sum_{k=1}^{K} y_{kt} = 1 \qquad t = 1, 2, \dots T \qquad (8)$$

$$D_t = \alpha - \beta\sum_{k=1}^{K}(n_k)^{\gamma} y_{kt} \qquad t = 1, 2, \dots T \qquad (9)$$

$$R_t = \alpha\sum_{k=1}^{K} n_k y_{kt} - \beta\sum_{k=1}^{K}(n_k)^{\gamma+1} y_{kt} \qquad t = 1, 2, \dots T \qquad (10)$$

$$y_{kt} \in \{0, 1\} \qquad k = 1, 2, \dots K;\ t = 1, 2, \dots T \qquad (11)$$

5. MODEL III: AGGREGATE PLANNING WITH MARKETING AND FINANCE ASPECTS

The aggregate planning model presented above incorporates marketing considerations through the determination of optimal prices but does not consider the feasibility of the plan from a financial perspective. Indeed, in a practical setting a firm must also consider the impacts of the sales and operations plan on working capital and cash flows. For example, the finance department determines a minimum cash balance that must be maintained to meet period-by-period payments (e.g., salaries, lease payments, etc.). The aggregate plan must consider this threshold so that the solution does not require expenditures beyond a certain limit. Furthermore, the expenses incurred in the aggregate plan are often fulfilled through loans. Loan limits and interest paid must also be considered when determining an optimal production schedule.

Financial information is typically reported using accrual basis and/or cash basis accounting. Each basis provides useful information for managers. Accrual accounting recognizes revenues when earned, regardless of when cash is collected, and expenses when incurred, regardless of when cash is paid. On the other hand, cash basis accounting tracks cash flows which directly impact the entity's liquidity. Our extended aggregate planning model includes measures using both bases. In what follows, we will use the terms "revenues" and "expenses" in accrual accounting, and "cash receipts" and "cash expenditures" in cash basis accounting. Net earnings is a profitability measure under accrual accounting and is calculated as [revenues – expenses]. Revenues equal sales made during the period. Expenses typically are the cost of goods sold, inventory carrying costs, selling and administrative costs (including depreciation on productive assets), and interest on loans. Our model assumes no gains or losses from unusual items (e.g., disposal of plant assets, uninsured losses, etc.). To track cash flows and balances, cash receipts equal all sales revenues collected during the period, regardless of the actual sale period. Cash expenditures include the cost of goods sold, inventory carrying costs, selling and administrative costs (excluding depreciation), and any interest on loans. We extend the model by defining the following input parameters:

CB_{min}	Minimum allowable cash balance in any period ($)
CB_0	Initial cash balance ($)
LOC	Borrowing limit on a line of credit ($)
dsc	Discount to customers for timely (i.e., during sale month) payment (%)
cs_t	Historical collection percentages *t* periods after sale month (%), t = 1, 2
f_t	Salaries and other recurring fixed costs in period t ($), t = 1, 2, … T
dep_t	Depreciation in period t ($), t = 1, 2, … T
int	Interest rate on outstanding balance on line of credit (%/period)

We also need the following additional variables to capture cash flow relationships:

Rec_t	Cash receipts in period *t* ($), t = 1, 2, … T
Exp_t	Cash expenditures in period *t* ($), t = 1, 2, … T
CB_t	Cash balance, before any borrowing, at end of period *t* ($), t = 1, 2, …T

$$CB_t = CB_{t-1} + Rec_t - Exp_t \quad (12)$$

Since cash balance can be either negative or positive, we represent it, following standard linear programming modeling, as the difference of two nonnegative variables, as shown below (t = 1, 2, … T):

$$CB_t - CB_{min} = SC_t - DC_t \quad (13)$$

with the following interpretation:

SC_t	Surplus cash in period t (amount above CB_{min})
DC_t	Deficit cash in period t (amount needed to bring the balance up to CB_{min})

Cash receipts in period t $(t = 1, 2, \ldots T)$ may be calculated as:

$$Rec_t = cs_2\, R_{t-2} + cs_1\, R_{t-1} + (1 - dsc)(1 - cs_2 - cs_1)R_t \quad (14)$$

Here, we assume that customers are allowed two periods (months) to fulfill payments on sales invoices. This assumption follows common industry practice where customers are typically allowed 60 days to pay. Also, following industry practice, if payment is made during the period of sale, a discount (dsc) is applied. The percentages of revenue collected one period and two periods following the sale are represented by cs_1 and cs_2 respectively. We assume that the remaining percentage of the sales revenue, $(1 - cs_2 - cs_1)$, is collected during the period of sale. Cash expenditures in period *t* $(t = 1, 2, \ldots T)$ may be calculated as:

$$Exp_t = r\, LS\, N_t\, W_t + v\, LC\, O_t + c\, I_t + h\, H_t + l\, L_t + m(P_t + O_t) + f_t + int\, DC_{t-1} \quad (15)$$

To compute net earnings, we need the following definitions that pertain to accrual accounting:

Rev_t	Revenues in period t ($), t = 1, 2, … T
Ex_t	Expenses in period t ($), t = 1, 2, … T
NE_t	Net earnings in period t ($), t = 1, 2, … T

$$NE_t = Rev_t - Ex_t \quad (16)$$

Revenues in period t $(t = 1, 2, \ldots T)$ may be calculated as:

$$Rev_t = R_t \quad (17)$$

Expenses in period t $(t = 1, 2, \ldots T)$ may be calculated as:

$$Ex_t = r\, LS\, N_t\, W_t + v\, LC\, O_t + c\, I_t + h\, H_t + l\, L_t + m(P_t + O_t) + f_t + dep_t + int\, DC_{t-1} \quad (18)$$

The first six terms in Eqn. (18) are derived from Eqn. (1) and reflect the costs that were included in the traditional aggregate planning problem. They are regular-time and overtime wages, inventory carrying costs, hiring and layoff costs, and material costs. Additionally, there are terms for recurring fixed costs (f_t), typically selling, general, and administrative expenses, as well as for depreciation (dep_t). The final term in Eqn. (18) is the interest incurred on any outstanding balance on the line of credit. We include an additional constraint to enforce a limit on borrowing ($t = 1, 2, \ldots T$):

$$DC_t \leq LOC \tag{19}$$

Eqns. (2) – (11), along with the additional relationships above, i.e., Eqns. (12) – (19), and the non-negativity constraint Eqn. (20) below comprise the constraints of this extended model.

$$SC_t, DC_t \geq 0 \qquad t = 1, 2, \ldots T \tag{20}$$

Finally, whereas our objective previously was the maximization of gross profit, here we focus on maximizing total net earnings over the planning horizon. That is, Eqn. $(1')$ is replaced with the following objective function, Eqn. (21):

$$Maximize \ \sum_{t=1}^{T} NE_t \tag{21}$$

Note that some simplifying assumptions have been made in the model presented here. First, the model assumes that all selling and administrative costs are *fixed*. Variable selling and administrative costs could be incorporated by adding an input parameter perhaps based on a percentage of R_t or the number of units sold in Eqns. (15) and (18). Second, the model assumes that cash outflows occur in the same period as when the expense is recognized. However, if suppliers offer credit terms, then the cash outflow may lag the expense by one or more periods. This can easily be incorporated into the model in a manner similar to how cash receipts from sales were handled in Eqn. (14).

6. NUMERICAL EXAMPLE

The three aggregate planning models are summarized in Table 1.

Table 1 The three models

Model	Goal	Objective Function	Constraints
I. Traditional Aggregate Planning (AP)	*Minimize* AP Cost	Eqn. (1)	Eqns. (2) - (6)
II. AP with Marketing Aspects	*Maximize* Gross Profit	Eqn. $(1')$	Eqns. (2) – (11)
III. AP with Marketing & Finance Aspects	*Maximize* Net Earnings	Eqn. (21)	Eqns. (2) – (20)

Below, we provide a numerical example to illustrate these models.

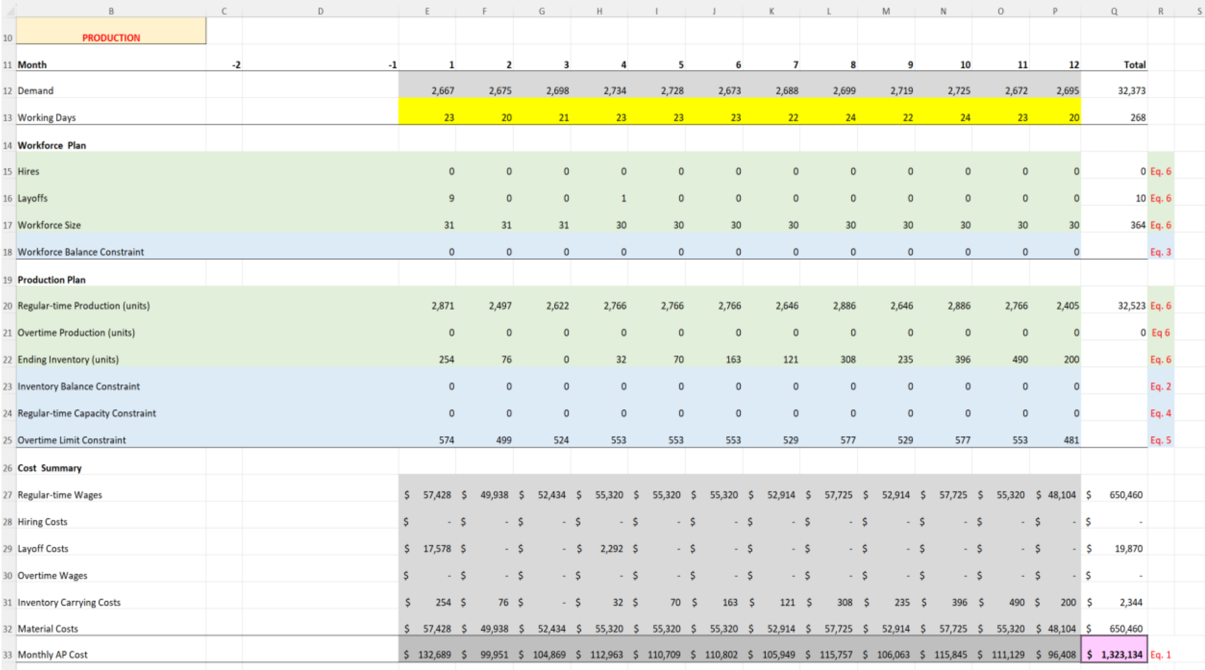
<u>Model I: Traditional AP</u>

Sample data for a 12-month planning horizon example is given in Table 2.

In addition, we assume the following demands for the 12 months: 2667, 2675, 2698, 2734, 2728, 2673, 2688, 2699, 2719, 2725, 2672, 2695. These values have been randomly drawn from a continuous uniform distribution [2666, 2788] to represent fluctuating demand. The lower and upper limits of this distribution have been chosen to match the lowest and highest values possible with the demand function of Eq. (9) and the prices $\{n_k\}$ that will be assumed later in Models II and III. Minimizing Eqn. (1) subject to the constraints in Eqns. (2) – (6) yields an optimal minimum AP cost of \$1,323,134 (Figure 1). Note that a desired ending inventory of 200 units is included in this example. The number of working days in each period is given in Row 13 below.

Table 2 Sample data for model I

Production Data				
Beginning workforce size, W_0	40	Regular-time wage rate, *r* (\$/hour)	\$	10
Labor content, *LC* (hours/unit)	2	Hiring cost, *h* (\$/hire)	\$	1,000
Length of regular-time shift, *LS* (hours/worker-day)	8	Layoff cost, *l* (\$/layoff)	\$	2,000
Production rate, *PR* (units/worker-day)	4	Overtime wage rate, *v* (\$/hour)	\$	15
Beginning inventory, I_0 (units)	50	Inventory carrying cost, *c* (\$/unit/month)	\$	1
Desired ending inventory, I_T (units)	200	Material cost, *m* (\$/unit)	\$	20
Overtime limit, *OL* (% of regular output)	20%			



10	PRODUCTION																
11	Month	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	Total	
12	Demand			2,667	2,675	2,698	2,734	2,728	2,673	2,688	2,699	2,719	2,725	2,672	2,695	32,373	
13	Working Days			23	20	21	23	23	23	22	24	22	24	23	20	268	
14	Workforce Plan																
15	Hires			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 6
16	Layoffs			9	0	0	1	0	0	0	0	0	0	0	0	10	Eq. 6
17	Workforce Size			31	31	31	30	30	30	30	30	30	30	30	30	364	Eq. 6
18	Workforce Balance Constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 3
19	Production Plan																
20	Regular-time Production (units)			2,871	2,497	2,622	2,766	2,766	2,766	2,646	2,886	2,646	2,886	2,766	2,405	32,523	Eq. 6
21	Overtime Production (units)			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq 6
22	Ending Inventory (units)			254	76	0	32	70	163	121	308	235	396	490	200		Eq. 6
23	Inventory Balance Constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 2
24	Regular-time Capacity Constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 4
25	Overtime Limit Constraint			574	499	524	553	553	553	529	577	529	577	553	481		Eq. 5
26	Cost Summary																
27	Regular-time Wages			$ 57,428	$ 49,938	$ 52,434	$ 55,320	$ 55,320	$ 55,320	$ 52,914	$ 57,725	$ 52,914	$ 57,725	$ 55,320	$ 48,104	$ 650,460	
28	Hiring Costs			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
29	Layoff Costs			$ 17,578	$ -	$ -	$ 2,292	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 19,870	
30	Overtime Wages			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
31	Inventory Carrying Costs			$ 254	$ 76	$ -	$ 32	$ 70	$ 163	$ 121	$ 308	$ 235	$ 396	$ 490	$ 200	$ 2,344	
32	Material Costs			$ 57,428	$ 49,938	$ 52,434	$ 55,320	$ 55,320	$ 55,320	$ 52,914	$ 57,725	$ 52,914	$ 57,725	$ 55,320	$ 48,104	$ 650,460	
33	Monthly AP Cost			$ 132,689	$ 99,951	$ 104,869	$ 112,963	$ 110,709	$ 110,802	$ 105,949	$ 115,757	$ 106,063	$ 115,845	$ 111,129	$ 96,408	$ 1,323,134	Eq. 1

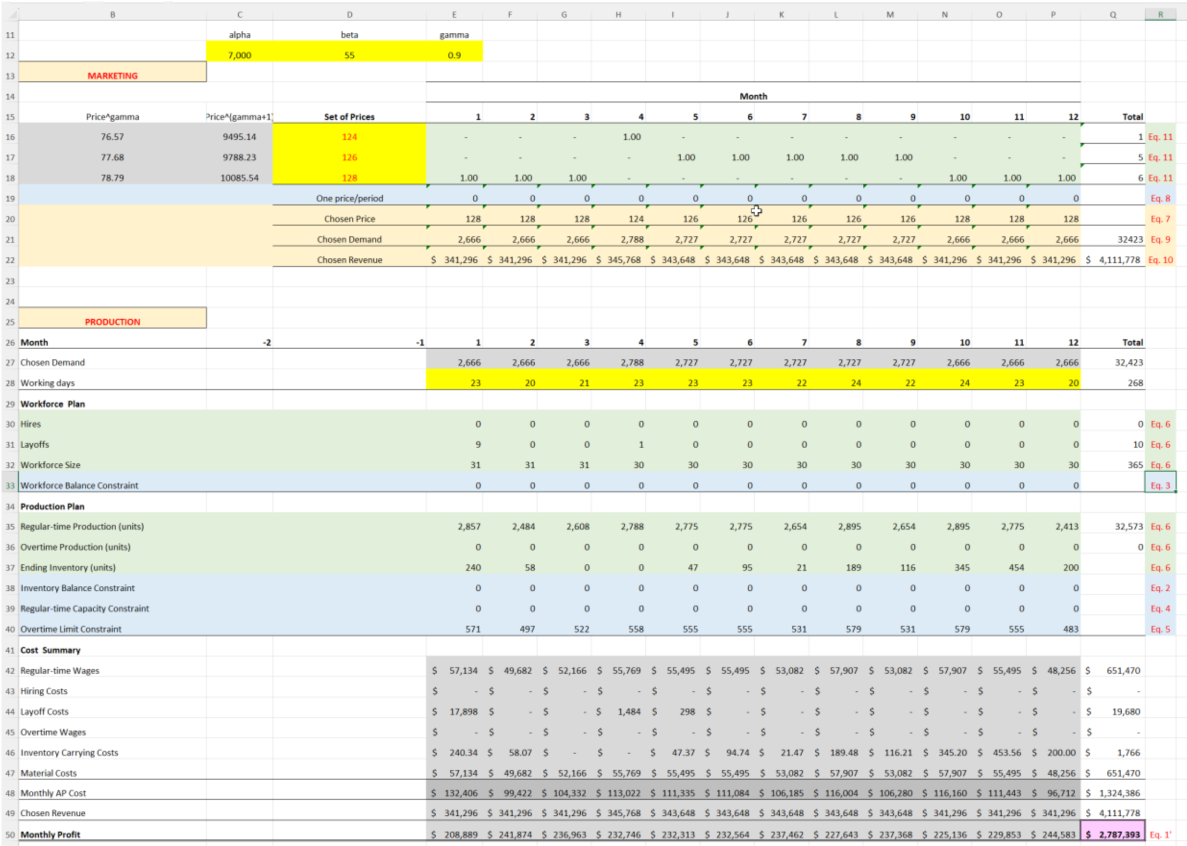
Figure 1 Model I: optimal solution

<u>Model II: AP with Marketing Aspects</u>

In addition to all the data in Model I, we also include the following:

$$\alpha = 7000; \beta = 55; \gamma = 0.9; K = 3 \text{ and } \{n_k\} = \{124, 126, 128\}.$$

Now maximizing Eqn. $(1')$ subject to the constraints in Eqns. (2)-(11) yields an optimal maximum gross profit of $2,787,393 (Figure 2). The optimal prices chosen are: {128, 128, 128, 124, 126, 126, 126, 126, 126, 128, 128, 128} (see Row 20).



11		alpha	beta	gamma													
12		7,000	55	0.9													
13	MARKETING																
14				Month													
15	Price^gamma	Price^(gamma+1)	Set of Prices	1	2	3	4	5	6	7	8	9	10	11	12	Total	
16	76.57	9495.14	124	-	-	-	1.00	-	-	-	-	-	-	-	-	1	Eq. 11
17	77.68	9788.23	126	-	-	-	-	1.00	1.00	1.00	1.00	1.00	-	-	-	5	Eq. 11
18	78.79	10085.54	128	1.00	1.00	1.00	-	-	-	-	-	-	1.00	1.00	1.00	6	Eq. 11
19			One price/period	0	0	0	0	0	0	0	0	0	0	0	0		Eq. 8
20			Chosen Price	128	128	128	124	126	126	126	126	126	128	128	128		Eq. 7
21			Chosen Demand	2,666	2,666	2,666	2,788	2,727	2,727	2,727	2,727	2,727	2,666	2,666	2,666	32423	Eq. 9
22			Chosen Revenue	$ 341,296	$ 341,296	$ 341,296	$ 345,768	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 341,296	$ 341,296	$ 341,296	$ 4,111,778	Eq. 10
23																	
24																	
25	PRODUCTION																
26	Month	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	Total	
27	Chosen Demand			2,666	2,666	2,666	2,788	2,727	2,727	2,727	2,727	2,727	2,666	2,666	2,666	32,423	
28	Working days			23	20	21	23	23	23	22	24	22	24	23	20	268	
29	Workforce Plan																
30	Hires			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 6
31	Layoffs			9	0	0	1	0	0	0	0	0	0	0	0	10	Eq. 6
32	Workforce Size			31	31	31	30	30	30	30	30	30	30	30	30	365	Eq. 6
33	Workforce Balance Constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 3
34	Production Plan																
35	Regular-time Production (units)			2,857	2,484	2,608	2,788	2,775	2,775	2,654	2,895	2,654	2,895	2,775	2,413	32,573	Eq. 6
36	Overtime Production (units)			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 6
37	Ending Inventory (units)			240	58	0	0	47	95	21	189	116	345	454	200		Eq. 6
38	Inventory Balance Constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 2
39	Regular-time Capacity Constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 4
40	Overtime Limit Constraint			571	497	522	558	555	555	531	579	531	579	555	483		Eq. 5
41	Cost Summary																
42	Regular-time Wages			$ 57,134	$ 49,682	$ 52,166	$ 55,769	$ 55,495	$ 55,495	$ 53,082	$ 57,907	$ 53,082	$ 57,907	$ 55,495	$ 48,256	$ 651,470	
43	Hiring Costs			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
44	Layoff Costs			$ 17,898	$ -	$ -	$ 1,484	$ 298	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 19,680	
45	Overtime Wages			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
46	Inventory Carrying Costs			$ 240.34	$ 58.07	$ -	$ -	$ 47.37	$ 94.74	$ 21.47	$ 189.48	$ 116.21	$ 345.20	$ 453.56	$ 200.00	$ 1,766	
47	Material Costs			$ 57,134	$ 49,682	$ 52,166	$ 55,769	$ 55,495	$ 55,495	$ 53,082	$ 57,907	$ 53,082	$ 57,907	$ 55,495	$ 48,256	$ 651,470	
48	Monthly AP Cost			$ 132,406	$ 99,422	$ 104,332	$ 113,022	$ 111,335	$ 111,084	$ 106,185	$ 116,004	$ 106,280	$ 116,160	$ 111,443	$ 96,712	$ 1,324,386	
49	Chosen Revenue			$ 341,296	$ 341,296	$ 341,296	$ 345,768	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 341,296	$ 341,296	$ 341,296	$ 4,111,778	
50	Monthly Profit			$ 208,889	$ 241,874	$ 236,963	$ 232,746	$ 232,313	$ 232,564	$ 237,462	$ 227,643	$ 237,368	$ 225,136	$ 229,853	$ 244,583	$ 2,787,393	Eq. 1'

Figure 2 Model II: optimal solution

Model III: AP with Marketing & Finance Aspects

In addition to all the data in Model II, we also include the financial data given in Table 3.

Table 3 Additional sample data for model III

Financial Data		*Recurring monthly expenses, f*	
Annual interest rate on the line of credit, *int*	8%	General & administrative expenses*	$ 130,000
		Lease payment*	$ 4,000
Collections		Miscellaneous expenses	$ 2,000
Discount allowed for sale month, *dsc*	1%	Depreciation, *dep*	$ 3,000
Sale month, $1 - cs_1 - cs_2$	10%	Initial cash balance, CB_0	$ 300,000
First month following sale month, cs_1	75%	Minimum allowable cash balance, CB_{min}	$ 300,000
Second month following sale month, cs_2	15%	Borrowing limit on the line of credit, *LOC*	$ 400,000

**These two costs are doubled during the first six months of the planning horizon.*

We also assume that the sales revenues in the two months preceding the planning horizon are $400,000 and $380,000 respectively (see Cells C65 and D65). With these data, maximizing Eqn. (21) subject to constraints in Eqns. (2)-(20) yields optimal net earnings of $310,621. The optimal solution to this integrated model is shown in Figures 3-5 (it is broken up into three figures for space/display considerations, but it is really a single worksheet as can be seen from the row and column numbers). The optimal prices chosen are (see Row 30 in Figure 3): {128, 128, 128, 124, **124**, 126, 126, 126, 126, **126**, 128, 128}. Note that the **bold-faced** numbers are different from those in the solution to Model II, justifying the need to explicitly consider financial constraints in aggregate production planning. The impact of not considering the financial aspects can be illustrated by re-solving Model III (Marketing & Finance) with the selected prices forced to be equal to those found in Model II (Marketing only). The resulting net earnings value turns out to be lower in magnitude when financial aspects are not explicitly considered. In our numerical example, the corresponding figures were $310,621 and $310,580. While this difference may not appear significant in this example, it points out that considering financial aspects explicitly does result in an increase in net earnings. Finally, the Solver dialog for Model III is shown in Figure 6. (Here, Cell C7 contains the value of the desired ending inventory of 200.)

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
21		alpha	beta	gamma													
22		7,000	55	0.9													
23	MARKETING																
24				Month													
25	Price^gamma	Price^(gamma+1)	Set of Prices	1	2	3	4	5	6	7	8	9	10	11	12	Total	
26	76.57	9495.14	124	-	-	-	1.00	1.00	-	-	-	-	-	-	-	2	Eq. 11
27	77.68	9788.23	126	-	-	-	-	-	1.00	1.00	1.00	1.00	1.00	-	-	5	Eq. 11
28	78.79	10085.54	128	1.00	1.00	1.00	-	-	-	-	-	-	-	1.00	1.00	5	Eq. 11
29			One price/period	0	0	0	0	0	0	0	0	0	0	0	0		Eq. 8
30			Chosen Price	128	128	128	124	124	126	126	126	126	126	128	128		Eq. 7
31			Chosen Demand	2,666	2,666	2,666	2,788	2,788	2,727	2,727	2,727	2,727	2,727	2,666	2,666	32546	Eq. 9
32			Chosen Revenue	$ 341,296	$ 341,296	$ 341,296	$ 345,768	$ 345,768	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 341,296	$ 341,296	$ 4,116,250	Eq. 10

Figure 3 Model III optimal solution: marketing

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
34																	
35	PRODUCTION																
36	**Month**	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	Total	
37	Chosen Demand			2,666	2,666	2,666	2,788	2,788	2,727	2,727	2,727	2,727	2,727	2,666	2,666	32,546	
38	Working Days			23	20	21	23	23	23	22	24	22	24	23	20	268	
39	**Workforce Plan**																
40	Hires			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 6
41	Layoffs			9	0	0	1	0	0	0	0	0	0	0	0	10	Eq. 6
42	Workforce Size			31	31	31	30	30	30	30	30	30	30	30	30	366	Eq. 6
43	Workforce Balance constraint			0	0	0	0	0	0	0	0	0	0	0	0		Eq. 3
44	**Production Plan**																
45	Regular-time Production (units)			2,857	2,484	2,608	2,790	2,790	2,790	2,669	2,911	2,669	2,911	2,790	2,426	32,696	Eq. 6
46	Overtime Production (units)			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 6
47	Ending Inventory (units)			240	58	0	2	3	66	7	191	133	317	440	200	1,657	Eq. 6
48	Inventory Balance Constraint			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 2
49	Regular-time Capacity Constraint			0	0	0	0	0	0	0	0	0	0	0	0	0	Eq. 4
50	Overtime Limit Constraint			571	497	522	558	558	558	534	582	534	582	558	485	6,539	Eq. 5
51	**Cost Summary**																
52	Regular-time Wages			$ 57,134	$ 49,682	$ 52,166	$ 55,801	$ 55,801	$ 55,801	$ 53,375	$ 58,227	$ 53,375	$ 58,227	$ 55,801	$ 48,522	$ 653,911	
53	Hiring Costs			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
54	Layoff Costs			$ 17,898	$ -	$ -	$ 1,449	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 19,347	
55	Overtime Wages			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
56	Inventory Carrying Costs			$ 240.34	$ 58.07	$ -	$ 1.59	$ 3.19	$ 65.86	$ 7.24	$ 191.22	$ 132.60	$ 316.58	$ 440.25	$ 200.00	$ 1,657	
57	Material Costs			$ 57,134	$ 49,682	$ 52,166	$ 55,801	$ 55,801	$ 55,801	$ 53,375	$ 58,227	$ 53,375	$ 58,227	$ 55,801	$ 48,522	$ 653,911	
58	Monthly AP cost			$ 132,406	$ 99,422	$ 104,332	$ 113,053	$ 111,605	$ 111,667	$ 106,757	$ 116,645	$ 106,882	$ 116,770	$ 112,042	$ 97,245	$ 1,328,826	
59	Chosen Revenue			$ 341,296	$ 341,296	$ 341,296	$ 345,768	$ 345,768	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 341,296	$ 341,296	$ 4,116,250	
60	**Monthly Profit**			$ 208,889	$ 241,874	$ 236,963	$ 232,715	$ 234,163	$ 231,980	$ 236,891	$ 227,002	$ 236,766	$ 226,877	$ 229,254	$ 244,051	**$ 2,787,424**	

Figure 4 Model III optimal solution: production

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
62																	
63	FINANCE																
64	**Month**	-2	-1	1	2	3	4	5	6	7	8	9	10	11	12	Total	
65	Chosen Revenue	$ 400,000	$ 380,000	$ 341,296	$ 341,296	$ 341,296	$ 345,768	$ 345,768	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 343,648	$ 341,296	$ 341,296	$ 4,116,250	
66	Collections:																
67	*Sale Month*	$ 39,600	$ 37,620	$ 33,788	$ 33,788	$ 33,788	$ 34,231	$ 34,231	$ 34,021	$ 34,021	$ 34,021	$ 34,021	$ 34,021	$ 33,788	$ 33,788	$ 407,509	
68	*First Month after Sale Month*		$ 300,000	$ 285,000	$ 255,972	$ 255,972	$ 255,972	$ 259,326	$ 259,326	$ 257,736	$ 257,736	$ 257,736	$ 257,736	$ 257,736	$ 255,972	$ 3,116,216	
69	*Second Month after Sale Month*			$ 60,000	$ 57,000	$ 51,194	$ 51,194	$ 51,194	$ 51,865	$ 51,865	$ 51,547	$ 51,547	$ 51,547	$ 51,547	$ 51,547	$ 632,049	
70	**Cash Receipts**			**$ 378,788**	**$ 346,760**	**$ 340,954**	**$ 341,397**	**$ 344,751**	**$ 345,212**	**$ 343,622**	**$ 343,304**	**$ 343,304**	**$ 343,304**	**$ 343,071**	**$ 341,307**	**$ 4,155,774**	Eq. 14
71	Monthly AP Cost			$ 132,406	$ 99,422	$ 104,332	$ 113,053	$ 111,605	$ 111,667	$ 106,757	$ 116,645	$ 106,882	$ 116,770	$ 112,042	$ 97,245	$ 1,328,826	
72	Administrative Salaries			$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 260,000	$ 130,000	$ 130,000	$ 130,000	$ 130,000	$ 130,000	$ 130,000	$ 2,340,000	
73	Lease Payment			$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 8,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 72,000	
74	Miscellaneous Expenses			$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 2,000	$ 24,000	
75	Interest on Line of Credit Outstanding			$ 157	$ 309	$ 531	$ 809	$ 1,054	$ 1,297	$ 625	$ 21	$ -	$ -	$ -	$ -	$ 4,803	
76	Depreciation			$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 3,000	$ 36,000	
77	**Cash Expenditures**			**$ 402,406**	**$ 369,422**	**$ 374,332**	**$ 383,053**	**$ 381,605**	**$ 381,667**	**$ 242,757**	**$ 252,645**	**$ 242,882**	**$ 252,770**	**$ 248,042**	**$ 233,245**	**$ 3,764,826**	Eq. 15
78	Cash at Beginning of Month (w/o Borrowing)			$ 300,000	$ 276,382	$ 253,720	$ 220,342	$ 178,686	$ 141,832	$ 105,377	$ 206,242	$ 296,901	$ 397,323	$ 487,856	$ 582,885	$ 3,447,547	
79	Cash at End of Month (w/o Borrowing)			$ 276,382	$ 253,720	$ 220,342	$ 178,686	$ 141,832	$ 105,377	$ 206,242	$ 296,901	$ 397,323	$ 487,856	$ 582,885	$ 690,948	$ 3,838,494	Eq. 12
80	Minimum Allowable Cash Balance			$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 300,000	$ 3,600,000	
81	Surplus Cash			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 97,323	$ 187,856	$ 282,885	$ 390,948	$ 959,012	Eq.20
82	Deficit Cash			$ 23,618	$ 46,280	$ 79,658	$ 121,314	$ 158,168	$ 194,623	$ 93,758	$ 3,099	$ -	$ -	$ -	$ -	$ 720,518	Eq.20
83	Cash Flow Constraint			$ 0	$ 0	$ 0	$ 0	$ (0)	$ (0)	$ (0)	$ (0)	$ (0)	$ (0)	$ (0)	$ (0)	$ (0)	Eq. 13
84	Line of Credit (LOC) Limit			$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000	$ 400,000		
85	LOC Constraint			$ 376,382	$ 353,720	$ 320,342	$ 278,686	$ 241,832	$ 205,377	$ 306,242	$ 396,901	$ 400,000	$ 400,000	$ 400,000	$ 400,000		Eq. 19
87	**Revenues**			**$ 341,296**	**$ 341,296**	**$ 341,296**	**$ 345,768**	**$ 345,768**	**$ 343,648**	**$ 343,648**	**$ 343,648**	**$ 343,648**	**$ 343,648**	**$ 341,296**	**$ 341,296**	**$ 4,116,250**	Eq. 17
88	**Expenses**			**$ 405,564**	**$ 372,731**	**$ 377,863**	**$ 386,861**	**$ 385,659**	**$ 385,965**	**$ 246,382**	**$ 255,666**	**$ 245,882**	**$ 255,770**	**$ 251,042**	**$ 236,245**	**$ 3,805,630**	Eq. 18
89	Net Earnings			$ (64,268)	$ (31,435)	$ (36,568)	$ (41,094)	$ (39,892)	$ (42,317)	$ 97,266	$ 87,982	$ 97,766	$ 87,877	$ 90,254	$ 105,051	**$ 310,621**	Eq. 16/21

Figure 5 Model III optimal solution: finance

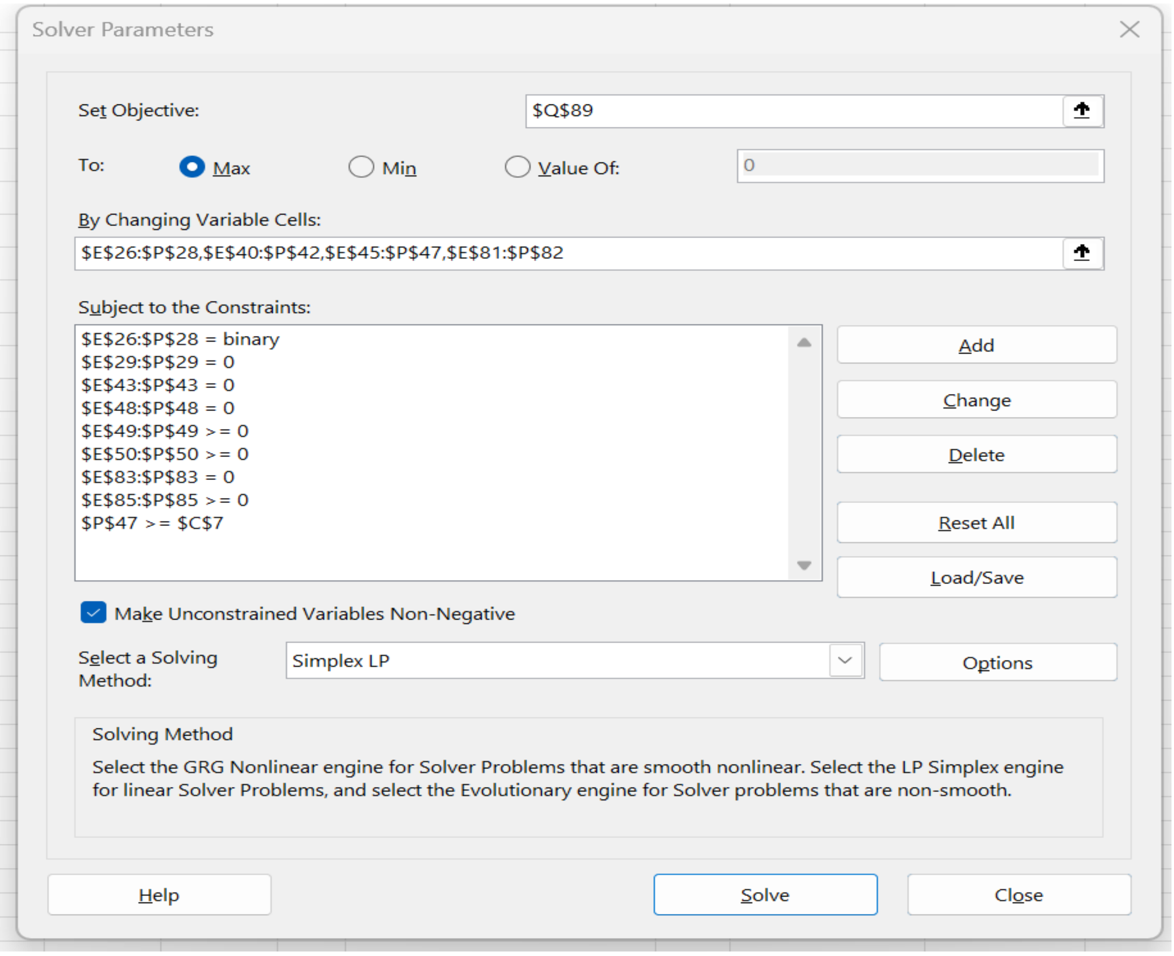


Figure 6 Model III solver dialog

7. CONCLUSION

By presenting an extension of the traditional aggregate production planning model that also considers marketing and financial restrictions and goals, our approach is helpful toward addressing the silo mentality of functional areas during the sales & operations process. We address the gap between the research literature and industrial practice discussed by Buxey (2003) and daSilva et al. (2006) by presenting a model that includes practical considerations managers face when determining an aggregate plan. We replace the traditional cost minimization objective with one that maximizes total net earnings. Our approach maintains linearity of the model, making it amenable to the widely available Excel Solver, and demonstrates the ease of managerial applicability. Given below are a couple of limitations of this study and suggestions for future work:

1. When solving this model using the native Solver in Microsoft Excel, one is limited by the number of variables that the software can handle. This is especially apparent when determining the optimal price for each period since the discretization of the demand function can be made finer by increasing the number of distinct prices that the model could choose from. This limitation could be resolved by using a more capable solver, e.g., OpenSolver (Mason (2012)), but more widespread applicability of the model is likely to be compromised.
2. Our approach here assumes that the demand function does not change seasonally and is only a function of price. It would be interesting to incorporate a more complex demand function that considers other external influences such as time of year (seasonality) or other significant economic factors.

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