Risk management in integrated budgeting-scheduling models for the batch industry

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ABSTRACT

This paper addresses integrated scheduling, planning and budgeting with financial risk management in the batch chemical process industries. A cash flow and budgeting model is coupled with an advanced planning and scheduling procedure using a two-stage stochastic formulation. The results of the integrated model are compared with the results of the sequential use of scheduling followed by budgeting. Finally the model is extended to manage financial risk.

1. INTRODUCTION

In the last 20 years, a number of models have been developed to perform short term scheduling and longer term planning of batch plant production to maximize economic objectives (Shah, 1998). On the other hand, budget models for financial control emerged earlier than operation schedules to time payments, arrange loans and eventually to invest in marketable securities the excess of cash at a given instant which is needed later (Orgler, 1970; Srinivasan, 1986). The importance of cash management has been recognized more than half a century ago. For example, Howard and Upton (1953) stated that "The effective control of cash is one of the most important requirements of financial management. Cash is the lifeblood of business enterprise, and its steady and healthy circulation throughout the entire business operation has been shown repeatedly to be the basis of business solvency". However, this knowledge remained confined to the financial management divisions of the companies and has not percolated into the design/operations activities.

Scheduling/planning on one hand and budgeting on the other have been treated as separate problems and normally implemented in a sequential way. The output from scheduling/planning (timing and amount produced) obtained maximizing some profit function, is used to determine accounts payable (raw material, labor, etc.) and the accounts receivable (proceeds from sales, etc), which in turn is an input data for the budgeting problem. Thus, with the lack of adequate enterprise computer-aided systems capable of managing optimally the working capital, the financial officers make decisions using out of date, estimated or anecdotal information (Badell and Puigjaner, 1998).

The integration of both activities to use a single one-step procedure seems therefore reasonable even at first glance. For example, it is evident that a good schedule may sometimes

create financial stress because at the level of budgeting, financing sources are needed, while some other schedule may be more profitable because it does not generate a severe impact in the budgeting side. In this paper such integration of a cash flow management model with an advanced planning and schedule (APS) procedure is performed and tested.

Another issue is financial risk. Risk, in financial circles is associated to the variability of profit. In an alternative definition, risk is the probability of not reaching a certain aspiration level of profit. Thus variability, which penalizes equally profitable and unprofitable scenarios, is substituted by the analysis of the cumulative probabilities at different aspiration levels. Some systematic procedures based mostly on mathematical programming have been developed to manage risk at the design stage (Barbaro and Bagajewicz, 2002a,b). In financial circles, the use of decision trees and ad-hoc trial and error is more common. In this article financial risk is discussed and managed.

2. INTEGRATED MODEL FOR SCHEDULING&PLANNING AND BUDGETING

The proposed framework is shown through a specific case study. This case study consists of a batch specialty chemical plant with two different batch reactors. Here, each production recipe basically consists of the reaction phase. Hence, raw materials are assumed to be transferred from stock to the reactor, where several substances react, and, at the end of the reaction phase, products are directly transferred to lorries to be transported to different customers.

Plant product portfolio is assumed to be around 30 different products using up to 10 different raw substances. Production times are assumed to range from 3 to 30 hours. Product switch-over basically depends on the nature of both substances involved in the precedent and following batch. Cleaning time ranges from 0 up to 6 hours till not permitted sequences.

2.1 Scheduling&Planning Model
The problem to solve is a 13-week period. Equations 1 to 23 show schematically the scheduling&planning model. The first week is planned with known product demands and the others with known (regular) and estimated (seasonal) demands. Here, orders to be produced are scheduled considering set-up or cleaning times. Thus, the sequence of orders to satisfy customer requirements and the schedule assignement that minimises the overall required cleaning time is calculated for the first week. The following weeks after the first are not exact. Indeed, they probably won't be executed as calculated, but their planning is useful to consider if coming orders will be satisfied. Here, no exact sequence is calculated.

The amount of raw materials and final products stored at every week-period are also monitored as a function of the amount stored in the precedent period, the amount bought or produced and the amount consumed or sold in that period. With this, the model is able to schedule raw materials orders.

(1) $\quad TPfw_e = \sum_o \sum_p TOP_p nx_{p,o,e} + \sum_o CT_{o,e}$

(2) $\quad TPfw_e \leq 168 \quad$ (week production time)

(3) $\quad CT_{o,e} = \sum_p \sum_{p'} CT_{p,p'} x_{p,o,e} x_{p',o-1,e} \quad o > 1$

$\quad\quad CT_{o,e} = 0 \quad$ (initial required cleaning time) $\quad o = 1$

(4) $\quad \sum_p x_{p,o,e} \leq 1$

(5) $\quad \sum_o x_{p,o,e} \le 1$

(6) $\quad \sum_p x_{p,o,e} \le \sum_p x_{p,o\text{-}1,e}$

(7) $\quad x_{p,o,e} \le nx_{p,o,e}$

(8) $\quad M \cdot x_{p,o,e} \ge nx_{p,o,e}$

(9) $\quad x_{p,o,'e1'} = 0 \quad$ if product p is of type 2

(10) $\quad x_{p,o,'e2'} = 0 \;$ and $x_{p,o,'e3'} = 0 \;$ if product p is of type 1

(11) $\quad TP_{k,e} = \sum_i TOP_i \cdot nw_{i,k,e} \quad k > 1$

(12) $\quad TP_{k,e} \le (168 - \theta_k) \quad$ (week production time) $\quad k > 1$

(13) $\quad w_{i,k,e} \le nw_{p,k,e} \quad k > 1$

(14) $\quad M \cdot w_{i,k,e} \ge nw_{p,k,e} \quad k > 1$

(15) $\quad w_{p,k,'e1'} = 0 \quad$ if product p is of type R2 $\quad k > 1$

(16) $\quad w_{p,k,'e2'} = 0 \;$ and $w_{p,k,'e3'} = 0 \;$ if product p is of type R1 $\quad k > 1$

(17) $\quad nw_{p,k=1,e} = \sum_o nx_{p,o,e}$

(18) $\quad w_{p,k=1,e} = \sum_o x_{p,o,e}$

(19) $\quad satisfaction_{i|i \ne 'one\text{-}off'} = 1$

(20) $\quad P\_Stock_{p,k} = P\_Stock_{p,k-1} + \sum_e B_e \cdot nw_{p,k,e} - \sum_{\substack{i|k=D_i+\delta_i \\ i|prod_i=p}} qp_i \cdot satisfaction_i$

$\quad\quad P\_Stock_{p,k} \ge 0$

(23) $\quad R\_Stock_{r,k} = R\_Stock_{r,k-1} - \sum_e \sum_{p|R_p=r} qr_p \cdot nw_{p,k,e} + qb_r \cdot rb_{r,k-1}$

$\quad\quad R\_Stock_{r,k} \ge 0$

2.2 Budgeting Model

Short-term Budgeting decisions can be taken every week-period. Production expenses during the week consider an initial stock of raw material and products. An initial working capital is considered beneath which a short-term loan must be requested, if needed. The minimum net cash flow allowed in every week-period is set taking into account the variability of cash outflow.

Among others, the production liabilities incurred in every week-period are because of the purchasing of raw materials and other fixed costs, while the income comes form the sale of products. A short term financing source is represented by a constrained open line of credit. Under an agreement with the bank, loans can be obtained at the beginning of any period and are due after one year at a monthly interest rate depending on the bank agreement (i.e 5%). This interest rate might be a function of the minimum cash. The portfolio of marketable securities held by the firm at the beginning of the first period includes several sets of securities with known face values in monetary units (mu) and maturity week-period k' incurred at month-period k. All marketable securities can be sold prior to maturity at a discount or loss for the firm. Introducing these equations into the budgeting model presented give an integrated model for production scheduling and planning and enterprise budgeting.

(24) $\quad Wcash_k \geq Min\_Cash$

(25) $\quad R\_Liability_{k-1} = \sum_r qb_r \cdot rb_{r,k} \cdot CostRaw_r$

(26) $\quad Exogenous\_cash_k = \sum_{i|D_i=k} satis_i \cdot qp_i \cdot SaleP_i$

(27) $\quad Debt_k \leq Max\_debt$

$\qquad Debt_k = Debt_{k-1} + Borrow_k - Out\_Debt_k + F \cdot Debt_{k-1}$

(28) $\quad MS\_net\_cashflow_k = -\sum_{k'=k+1}^{13} \left(MSinv_{k',k} - MSsale_{k',k} \right)$

$$+ \sum_{k'=1}^{k-1} \left(d_{k,k'} MSinv_{k,k'} - e_{k,k'} MSsale_{k,k'} \right)$$

(29) $\quad Exogenous\_cash_k - R\_liability_k + Borrow_k - Out\_Debt_k$

$\qquad MS\_net\_CashFlow_k + WCash_{k-1} + others_k = WCash_k$

2.3. Objective function

For m = 3, 6, 9 and 12, cash is withdrawn from the system, for example in the form of shareholder dividend emission. Objective function will consist of maximising these dividends as follows:

(36) $\quad others_{m=3,6,9,12} = -share\_div_l \quad l = 1,2,3,4$

$\qquad O.F. = \max \sum_l \alpha_l \cdot share\_div_l$

3. RESULTS OF THE INTEGRATION OF MODELS

The model was run for a plant product portfolio of 20 different orders using up to 10 different raw substances. The model is implemented in GAMS/CPLEX in a 1 GHz machine using about 190 CPU seconds.

The results of solving the integrated model with the sequential application of both models (Scheduling&planning and budgeting) separately were compared. The overall cash withdrawn using the integrated model is of 203196 m.u. while the resolution of the sequenced problems gives earnings of just 185588 m.u. The schedules and products produced are different (not shown for space reasons). Figure 1 shows the profile of marketable securities and debts of the enterprise during the three first months of the plan, period prior to the first dividend emission of the year. The integrated model manages to change production planning to be able to invest more cash on marketable securities and reduce the debt.
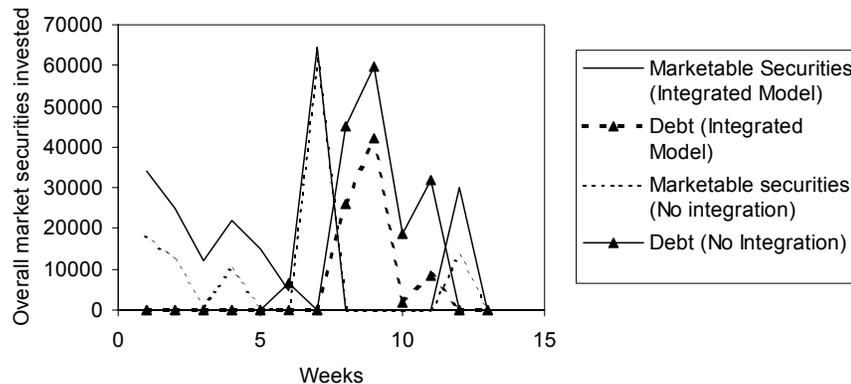

Figure 1. Comparison of the integrated model for scheduling&planning and budgeting with the use of independent models.

4. STOCHASTIC MODEL

Two essential features characterize the stochastic model: the uncertainty in the problem data and the sequence of decisions. Here, as for the planning model product demand is considered a random variable with a normal probability distribution. As for the short-term budgeting model, the delivered product payments and the 'others' costs of production aside from raw liabilities are also considered random. In the long-term budgeting model, the expected production profit and production cost are random. First stage decision variable are the ones concerning the planning & scheduling meanwhile the variables concerning the budgeting are considered second stage.

5. FINANCIAL RISK

The Financial risk associated with a specific planning solution under uncertainty is defined as the probability of not meeting a certain target profit level, referred to as Ω (Barbaro and Bagajewicz, 2002a,b). The use of the concept of downside risk, Drisk(x,Ω), in the way introduced by Eppen et al. (1989), is applied in this work. Drisk(x,W) is used to control financial risk at different targets W. The details of the implementation are in Barbaro and Bagajewicz (2002). The financial risk curve obtained for the stochastic model is shown in Figure 2.
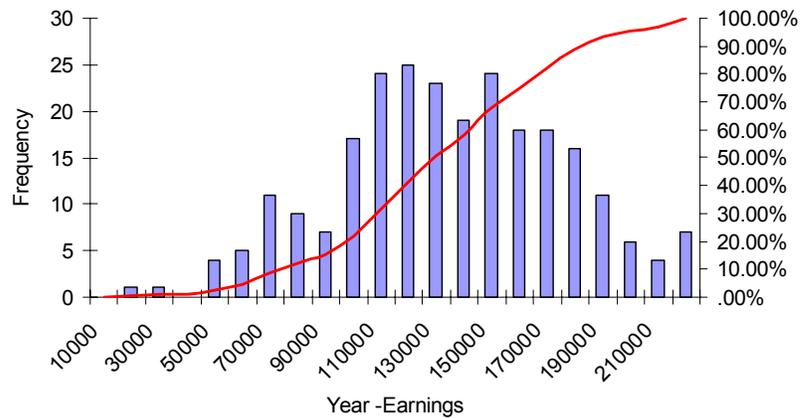
Figure 2. Risk curve when no risk minimization is used.

It is considered that the minimum target the enterprise must reach is of 50000, as fewer earnings will not compensate overall enterprise depreciation. Thus risk was minimized at this target. Figure 3 shows the entire risk curves and shows a blown up section of these curves.
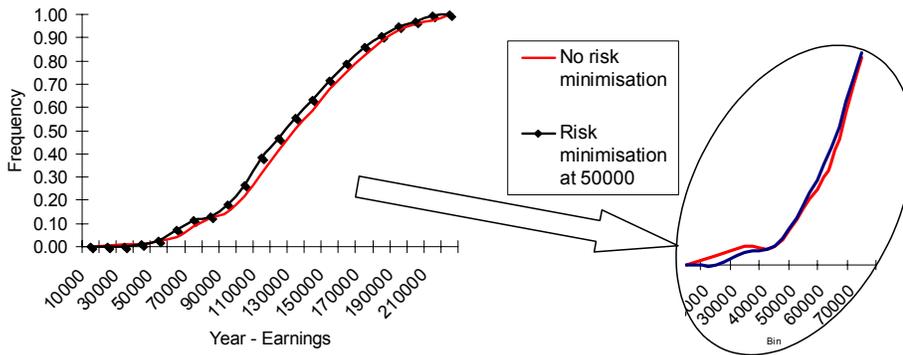
Figure 3. Risk curve when no risk minimization is used.

5. CONCLUSIONS

This paper has addressed the importance of integrating scheduling and budgeting models. By means of a comparison using a case study, it has been shown that significant improvements are possible as compared to the use of scheduling models followed by budgeting models. It has also been illustrated how a stochastic model can be used to manage financial risk.

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