Joint Financial and Operating Scheduling/Planning in Industry

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Abstract
This paper addresses the implementation of financial cross functional links with the supply chain operations and investment activities at plant level when scheduling and budgeting in short term planning in batch process industries. The target is to obtain trade-off solutions preserving at most the profit and liquidity while satisfying customers. The platform built combines a deterministic cash management model with an advanced schedule algorithm by MILP formulation. This methodology heightens the decision-making capacity of the CEO (chief executive officer) and CFO (chief financial officer) in complex scenarios. The benefits of this work are shown through a case study that illustrates the modelling framework and procedures necessary to implement a financial/supply chain methodology to aid top-level staff when planning and budgeting.

Keywords: Planning, budgeting, cash management, batch industry, retrofitting

1. Introduction
The aim of this work is to propose the use of advanced planning and schedule (APS) tools to model and change the current position of the financial and process managers during complex interconnected decision-making in chemical process industries (Badell and Puigjaner, 2001). The process systems engineering community commonly has been using net present value (NPV), internal rate of return (IRR) and/or payback rate (PR) to evaluate investments. However, when process managers propose plant retrofits usually do not pay attention about the overall status and synchronization of enterprise finances.

2. The financial problem formulation
The batch chemical processes possess a great inherent flexibility. This flexibility is transformed in complexity to its cash flow management due to the large product portfolio, assortment of material resources, equipment and manpower management. The engineering community has been using different metrics for assessing the investment return of potential projects or assets. Whatever metric used, it is possible the integrated projection of future cash flows reduced to present values. The investment must earn more than the cost of capital to be worthwhile.

On the other hand the financial community uses different economic ratios and performance metrics during sequential analysis by functions when distributing financial

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resources in a company. However, these sequentially calculated cash flows and those regarding investments proposed by process engineers are not integrated in a model to balance and fit the influence of one in others. Even some now frequently metrics, such as risky value to investment ratio (VIR), remain with sequential approach. However, some signs of change have appeared supporting cash flow management, budget and a more integrated approach. Plans are often being substituted by budgets when the overall performance is followed. In addition to the enterprise-wide integration of decisions, enhancing directly shareholder value – without any intermediate metric – is the top priority today to look attractive to the investors at the stock market. Obviously what comes in and out – cash inflows/outflows – is unmistakable and consequently trends today give more weight to treasury and budget than to accounting and plans. The budget measures, besides the current assets, the real economic effectiveness of the financing, leveraging, plan fulfillment and financial operations. The fraction of resources spent from the budget on strategic support activities is used as an indicator of how well finance and executors, mainly cross-functional process teams, are supporting job objectives. Thus taking into account that net cash flow could only be determined accurately in retrospect, the expected future cash balance is the most reliable performance measure available today to set an objective to achieve. This is what the budget is in fact doing and even more, if optimization is applied, flattens the net cash flow profile.

3. Previous work in cash management models

The cash balances normally fluctuate due to the lack of synchronization between cash inflows (receipts from accounts receivable and cash sales) and outflows (payments on accounts and notes payable). The cash management problem consists of optimally financing net outflows through a line of credit, pledging accounts receivable, selling marketable securities or investing the net inflows in marketable securities considering yield and transaction costs. While in the area of deterministic models of cash management most of them were developed focusing more in the individual financial decision types, at the stochastic side two basic approaches were developed. Baumol’s model (1952) had an inventory approach assuming certainty. Cash was treated similarly as holding inventory and payments were assumed at a constant rate. On the contrary the Miller and Orr cash management model (1966), was based on the fact that perfect forecasts of cash were virtually impossible because the timing of inflows depend on payments of customers. In consequence a lower and upper bound of cash were calculated to create a safety stock. On the deterministic side, since the sixties linear programming was introduced to the area of finance to consider the intertemporal aspects in financial environment. Orgler (1969) proposed a deterministic model based on keeping minimum cash while all excess is invested in marketable securities.


A four month time horizon is chosen, divided unequally into four periods of 10,20,30 and 60 days, respectively; i.e. period 1 has 10 days, period 2 has 20 days, etc. Switchover times and cost between products is of special concern. In this case study it is studied the plant retrofit to improve the switch-over between products, reducing the cleaning time required, in order to be able to assume a higher product demand. First,
modifying and expanding Orgler’s budget model is analysed the maximum retrofit investment having a financial capacity limited by the liquidity requirements set by the CFO. Second, interacting the budgeting with the designed APS tool, a retrofit investment is proposed considering the expected future plant financial behaviour after the retrofit. The objective function, to maximise in time horizon $T$, is the sum of payments taking or not the prompt payment discounts, $X_{g,j}$ and marketable securities revenues, expressed by the difference between net yield and net lose when sold ($y_{i,j} - z_{i,j}$), deducting costs of the short term credit line, $w_{h,g}$ and of the retrofit loan, $R_g$. Technical coefficients $C, D, E, F$ adjust quantities depending on the timing of periods when actions incur in: maturity, $i$, payment, $g$, sales, $j$, credit, $h$, etc.

$$REVENUE = \sum_{i} C_{i,j} X_{x,i,j} + \sum_{j} \sum_{i} \left( D_{i,j} y_{i,j} - E_{i,j} z_{i,j} \right) - \sum_{g} F_{h,g} w_{h,g} - \sum_{g} R_g$$ (1)

Production expenses during the week will consider initial zero stock and raw material needs. The minimum net cash flow allowed ($M_j$), below which a short-term financing source must be found, is determined by the CFO taking into account the variability of cash outflow (100 $mu$). The following hard constraint is then introduced.

$$b_j > M_j \quad j = 1, \ldots, T$$ (2)

The portfolio of marketable securities held by the firm at the beginning of the first period includes several securities with known face values and maturity periods, only one maturing beyond the horizon (S1=250, S2=190, S3=1900, S4=1500, S5=2250). All marketable securities can be sold prior to maturity at a discount or loss for the firm. Revenues and costs associated with the transactions in marketable securities are given by technical coefficients $d_{i,j}$ and $e_{i,j}$ considering $D_{i,j}$ (net yield of investment in period $i$ maturing in period $j$); $E_{i,j}$ (net lose for selling securities in period $j$, maturing in period $i$).

$$\sum_{j=1}^{t} d_{i,j} y_{i,j} \quad i = 2, \ldots, T, \text{ where } d_{i,j} = 1 + D_{i,j}$$ (3)

$$\sum_{j=1}^{t} e_{i,j} z_{i,j} \leq S_i \quad i = 2, \ldots, T + 1, \text{ where } e_{i,j} = 1 + E_{i,j}$$ (4)

A short term financing source is represented by a constrained (850 $mu$) 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 of 0.5%. Early repayments are not permitted. The costs of taking a loan relevant for measuring the performance of the cash management decisions are given by technical coefficients $F_{h,g}$ where $h$ are the alternatives considered and $g$ the funding cost.

$$\sum_{g=1}^{T} F_{h,g} w_{h,g} \leq K_h \quad h = 1, \ldots, v$$ (5)

The payment decisions to be considered correspond to accounts payable with 2 percent 10 days, net 30 days terms of credit (2-10/N-30). All payments of raw materials must be fulfilled within the horizon (L1=803, L2=2409, L3=3212, L4=7227). It is assumed that all bills are received in the first half of the respective periods and that payments, including sales of final products, are made at the beginning of the periods. Any part of the bills can be paid either at the first ten days with a 2% discount or at face value after 30 days. It remains to be decided upon what part of the bills to pay in which period. The payments are constrained by the following equation:
The net cash flows expected in periods 1, 2, 3 and 4 are variable decisions decided depending on the scheduling solution. The minimum cash balance requirement for all four periods was assumed 100 \( mu \). Other receipts and disbursements as payroll, loan repayment or sales (6863 \( mu \) per month) are entered as time fixed net cash flows. A requirement that the average daily cash balance be at least a known figure is incorporated. The monthly retrofit credit cost is calculated as 
\[
\frac{i n (1+i)^{-1}}{12 n}
\]
is the medium term loan interest and \( n \) the years of loan repayment. Several possibilities to "balance" the cash budget in periods in terms of their respective cost can be obtained.

5. A Case Study in Batch Chemical Industry

The case study consists of a batch specialty chemical plant with two different batch reactors (R1 and R2), excerpted from a real industrial scenario. Each production recipe basically consists of the reaction phase. Hence, raw materials are 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 around 60 different products using up to 15 different substances. Production times range from 3 to 34 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. Here, plant retrofit to improve product switch-over is envisaged. The objective of the scheduling algorithm is to maximise in a week horizon (168 h) the benefit obtained from producing a number of products of the demand portfolio considering each product hourly contribution to profit (as rough-cut difference between price and cost of materials) \( B_i \) minus the cleaning cost \( CC_{i,i'} \), equation (7).

Objective Function
\[
\text{max } \sum B_i Y_i - \sum \sum \sum \sum CC_{i,i'} x_{i,k,e} x_{i,k-1,e}
\]  

where \( x_{i,k,e} \) is the assignment binary variable of batch \( i \) at position \( k \) in the sequence at equipment unit \( e \). This objective function is maximised subject to constraints of timing and batch sequence as follows,

\[\text{Schedule}\_\text{Ti min } g \]
\[
TF_{k,e} = TI_{k,e} + \sum_i TOP_i x_{i,k,e} + \sum_i CT_{i,i'} x_{i,k,e} x_{i,k-1,e} \geq k \geq 1
\]
\[
TF_{k,e} = TI_{k,e} + \sum_i TOP_i x_{i,k,e} \quad k=1; TI_{k,e} \geq TF_{k-1,e} \quad k \geq 1; TI_{k,e} = 0 \quad k=1
\]  

\[\text{Batch}\_\text{sequencing}\]
\[
\sum_k x_{i,k,e} = Y_i \quad ; \quad \sum_j x_{i,k,e} \leq 1 \quad ; \quad \sum_i x_{i,k,e} \leq \sum_i x_{i,k-1,e} \quad k \geq 1
\]  

where \( TOP_i \) is the processing time of batch \( i \), \( CT_{i,i'} \) the cleaning time when switching-over from product \( i \) to \( i' \), \( TF_{k,e} \) and \( TI_{k,e} \) the ending and initial times of job \( k \) in the sequence at equipment unit \( e \). This formulation, introducing aggregated variables for \( x_{i,k,e} x_{i,k-1,e} \), gives a MILP formulation that is solved using GAMS-CPLEX. In order to
solve the problem in an efficient way, firstly the six products with more hourly contribution to profit are scheduled and then the rest. This strategy, though might lose some optimality, improves revenues, profit and permits to solve the combinatorial explosion problem in less than 20 CPU s at a 1 GHz machine. The procedure concludes that the optimal number of products to be contemplated at plant is 10 out of the 13.

6. Retrofitting modelling

In order to increase plant capacity, production managers of the company claim to improve the product switchover times. This can be done investing on a new cleaning device. If done, switchover times can be reduced in a 60%. This investment needs 10000 mu supplied by external funds, so a short or medium term loan must be requested. The CEO of the company agrees with the new investment provided by the company finances, but with a hard constraint: during the repayment period monthly outputs must be not higher than a 2% of the present firm earnings. The CEO answer was based on the influence of cash flows of companies at stock market. A higher drop on earnings would show a bad look of the company.

CFO takes note of the guidelines and calculates that the repayments of the 10000 mu sought would be supported by the profit improvement made by the new devices and a 2% of the obtainable earnings calculated at the last budget, 19126 mu. It means 383 mu for repayments during the 4 months (96 per month) and leaving 18743 mu during the horizon time considered for the company. The CFO of the company needs to calculate what loan repayment span is best for this situation. If the loan is repaid very quickly, company charges are too high and would not fulfil the investors sought expectative on earnings that the CEO ordered to be preserved. If very slowly, the enterprise will pay more interests. With the purpose of making an analysis of the investment capability under the conditions of this chemical enterprise, it is used the budgeting model (equation 1 to 6) for different repayment spans and required revenues. It can be observed the impact on cash flows of the funding policy with the revenues obtained. The optimum repayment span is found where the enterprise net cash flow balances the least interest expenses for a 10000 mu loan subject to CEO constraints (Fig.1). Lets consider that a medium-term loan is negotiated at an 8% annual interest. The optimal repayment span of the loan will be 4 year to keep company earnings at the level set by the CFO. The repayments of 273 mu per month are 13130 yearly. Notice that to repay is included the profit improvement post retrofitting, 5031 mu/year. The budget of retrofitting period gives a net [equivalent] cash of 18759 mu, 2% less than prior retrofitting due to a tighten policy and 4 repayments in the horizon, 1092 mu.

As the production engineers did before demanding the retrofit to the superiority, the CFO should use the net present value method to evaluate investments in the production plant. Discounted production profit prevails over the investment in few years. NPV analysis concludes a 2 years repayment span, which consumes a 6% of the present earnings [a four years’ loan consumes a 2%], while its payback time is fulfilled at the beginning of the 3rd year [a four years’ loan payback time is 4 years]. So for the two years’ loan the investment consumes an extra 4% of earnings tightening more the company with regard to possible benefits of opportunity costs, additionally declining attraction to investors at the stock market. This effects were taken into account when
decision making was controlled by a joint budget and retrofit (B&R) analysis and not considered if the officer only evaluates by the NPV analysis. Figure 2 shows graphically this situation. A smoother cash profile causes less stress and lets more flexibility. Consequently, a single NPV analysis cannot satisfy the CEO conditions to invest.

![Figure 1. Enterprise financial capacity for retrofitting investment.](image)

![Figure 2. Earnings profile applying B&R analysis and NPV analysis.](image)

### 7. Conclusions and future work

A complex decision making scenario of the routine practice in batch chemical industries is simulated achieving optimal synchronization and cash flows balance. Not only synchronises inflows and outflows, it also ensures a safety cash stock solving peaks so making full use of the scheduling possibilities with finite resources. Thus CFO could effectively lead a “proactive” forward-looking management with computer budgeting systems. Armed with up to the minute information on the overall budget status, costs and schedules, allocation of resources, reschedules and cost of capital, the CFO is prepared and available to respond quickly to events as they arise. This work constitutes an advance in the challenge to link finance and liquidity with enterprise functionality.

**References**


