Modeling Joint Performance of Financial Budgets and Operative Plans in Supply Chains

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Abstract (extended)

A full length article next→

The hierarchical production planning (HPP), the classical procedure applied in supply chains (SC), decouples the planning and scheduling decisions from budgeting considerations, and decides first on planning and scheduling and then it simply performs the corresponding financial computations for budgeting. As opposed to this approach, here we show that one can obtain significant financial gains by considering both, plan and budget problems, simultaneously in a financial and operative simulation model. We present a simulation descriptive model in which the SC operation has a liquidity control (cash is retained at a safety level), while are tried the best options to invest the surplus if opportunities exist. To formalize the liquidity status in the financial model, are used the financial categories of balance sheet, that is, the current assets (CA), fixed assets (FA), current liabilities (CL), long term debt (LD) and equity (E), as recommended by Shapiro, 2001. The mathematical balance equation (CA+FA-CL–LD-E=0) controls the net flows of the firm's cash, making possible to control the updated liquidity in the integrated functional model. In this joint environment the movements of events related to financial SC activities that create the monetary flows, are freely permitted. Therefore, it is feasible to flatten the money outflow peaks moving production tasks in order to achieve the optimal earnings with synchronization of cash flows. On the budget side we manage simultaneously decisions concerning cash management, compensating balances, prompt/delayed payment of sales/liabilities, investments in marketable securities, credit line, loans, repayment policy, pledging, manpower wages, debts, retrofitting, new assets for bottleneck solutions, etc. (Badell et al., 2005; Romero et al. 2003, and Guillén et al., 2005). In this work we investigate several solution techniques with different performance measures in order to create a common modeling building block capable to represent operative and financial operations. Our objective is the development of the necessary scheduling concepts to remake the comprehensive understanding that should ultimately facilitate the modeling of complicated systems considering financial operations in the same manner as the operative tasks. In order to understand completely the behavior of a complex system, it is vital to understand the workings of its components to detect its analogies and differences and the key management regulation loops regarding to the enterprise functionality.

The theory of scheduling uses different types of methodologies like combinatorial procedures, simulation, graph techniques, network methods and heuristic approaches for addressing efficiently sequencing problems. However, the assignment problem has always been calculated in one dimension (timing units) when searching the best position of batch sequences. Historically, engineering computer aided scheduling tools explicitly represented in Gantt charts the resource time, gathering directly or indirectly the whole measurement responsibility, and forgetting its omnipotent money partner in off, left slave of previous production decisions, disoriented about the operative routine and practice and hence, mistaken during planning. Due to the fact that chief financial managers (CFO) basically need information about the batches interferences in plant during planning, the batch assignment in a scheduling simulation tool for financial planners can be represented as a black box during computations, ignoring the internal technological details, and recovering

these details subsequently if required (information about unit operations is available in the model). Regarding methodologies, and with the intention of making easier the modeling task, a normative assignment/sequencing solution was developed using a Symmetric/ Asymmetric Traveling Salesman Problem (TSP/ATSP) formulation that uses the overlapping times (or not overlapping times) between batches with economic weight in order to fulfill the scheduling task [Badell, Fernández and Puigjaner, 2000].

Schedules are generally evaluated by aggregate quantities that involve information about all jobs, resulting in one dimensional performance measures. Measures of schedule performance are usually function of the set of completion times in a schedule. The aggregate performance measures defined induced others, as makespan, mean flowtime, mean tardiness, maximum flowtime, maximum tardiness or the number of tardy jobs, being all of them a function of the set of job/plan completion times. These performance measures were denominated regular due to the fact that when the scheduling objective is to minimize *Z, Z* can increase only if at least one of the completion times in the schedule increases. These indicators played the role of intermediaries linking time-to-technology-to-cost assuming that, for example, minimum makespan can be extrapolated as maximum profit, being this not always true. Moreover, research is almost entirely dedicated to the study of regular intermediate performance measures. Besides mathematical exact solutions, limited to a small number of products owing to its complexity and high solution time, we also adapted schedulers to operate jointly with financial and operative tasks in professional advanced planning and scheduling systems APS. The APS approach relies on the creation of computer models that permit to schedule resources assuming finite capacity. Besides the exact solutions, APS systems can also work with heuristic procedures or with software based in distributed agents. This distributed architecture is promising taking into account that can easily search information allowing automated cross walks through the functional segments of specific data to support web order entry systems.

In chemical industry the recipes give the time guidelines for production. To represent the financial tasks we used financial “recipes” and created fictitious units that compile the financial issues in the same manner as production tasks do. Therefore, Gantt charts can depict financial operations joining together with the production operations representation. Moreover, there is no reason for not applying to finantial shedules the same achievements of production scheduling in Gantt charts: they can be handled interactively; they can be displayed with a desired granularity shown in clicked windows; and can even be interactively rescheduled. So plans and budgets can be easily modified, as well as the resulting profiles of financial resources like money or balance sheet. At present, it is not enough to integrate the SC measuring information of its performance with financial key performance indicators (KPI) as profit, costs, earnings, value added, etc. In this position KPIs assume a passive informative role. These optimal financial records obtained must go ahead determining a list of optimal enterprise-wide decisions. Where to place the money on hand also requires optimization techniques and today these decisions are determined freely, based in intuition, while liquidity preservation is a great unknown variable for all the staff. Here we measure the performance by means of a multidimensional aggregate quantity that jointly takes into account the timing of process, the cleaning tasks for the respective batch sequences, and the economic/financial value added during production in the SC. This permits to decide simultaneously the dominance of the most valuable assignments as a function of time & money. This time-money aggregate can be obtained calculating the “density” of profit per hour of completion time, which obviously is schedule dependent. We present the results of two cases of study, the first one mainly within an enterprise scope and the second one, within a detailed SC scope. The methodology compares the results of the decoupled models with the integrated one.

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1. Introduction

SC has become the protagonist in the operations of the current enterprise. To remain competitive each enterprise must operate its SC as a single inter-linked organization, placing toward this aim all areas and resources in order to achieve goals and objectives. The challenges faced by the industry are present inside enterprise resource planning, forecasting, demand management and SC network performance, which are related in the intend of looking for the optimization of the strategic and operational planning and scheduling. Today SC models determine which tasks to do at each moment giving a score of its performance. These models are no longer enough. Models must play a more active role, recommending also the optimal financial decisions for each new scenario and giving as output besides an optimized plan, an optimized budget. Therefore, although SCM's within integrated models have received increasing attention, they lack prediction and precision in their design in order to solve real problems. Managers must be careful**:** not integrating SC planning models could potentially cost more (in efficient trading and losses), than is gained in sales promotion (Kafoglis, 1999).

The new economy sets more obstacles to overcome by the industry, especially the batch chemical processes. Globalization has resulted in worldwide increasing competition. This happens when usual tools are suddenly getting old to gather the whole current scenario. Traditional financial and accounting systems do not capture and may not be able to capture the drivers that dominate the new economy. The increasingly efficient capital market cannot be managed with accounting systems that operate on a backward fashion and are unable to capture the entire set of enterprise values obtainable at value markets.

According to Grossman (2004), the challenges for the new millennium in chemical industry are the development of new products to achieve the value growth, the optimization of the SC to achieve the value preservation, and the improvement of global life cycle to maintain living viability. But up to now, in SC management (SCM) new solutions to old unsolved problems are not immediately obvious. Indeed, every SC has in parallel a financial chain (Shapiro, 2001). Additionally, we actively support that this financial chain creates the SC, letting it grow and multiplying it, or on the contrary, destroying it.

Nevertheless, despite being the financial chain the most expensive resource (Drucker, 1999), it is the less planned/budgeted, and the less supported by computer-aided simulators or optimizers (Badell & Puigjaner, 2000). A 70% of chief financial officers (CFO) work is supported on Excel spreadsheets, where data is manually collected. This unsolved problem remains when their position today is harder. It was recently remarked by the CFO News Research Services (1/6/2004)**:** CFOs are pressured by the senior management to produce more detailed budgets and forecasts, and to track performance data or key performance indicators (KPIs) with increasing relevancy, in "what if" scenarios and using longer time horizons to cut costs and drive profitability. Besides the lack of adequate automatic tools, the contents of these planning and budgeting reports have overdependence on key personnel for version control, collaboration, consolidation of works and many other facts.

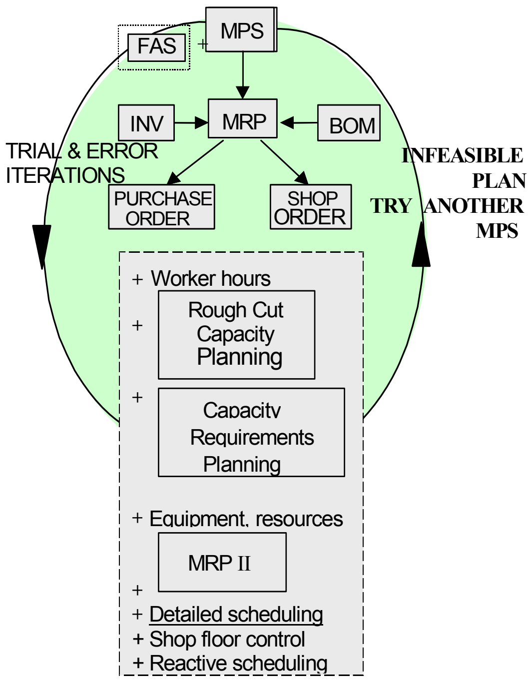
The software systems that could be useful nowadays are those capable of preserving the firm's liquidity while providing a quick and optimal response to orders, through the optimization of delivery dates and price-time tradeoffs solutions. Reactive transaction-oriented scheduling can be attained with web-based interfaces, guided by autonomous agents to connect business to factory scenario. Here the problem is that you cannot say to a customer during online negotiations at real time: "…please, wait while I run an exact model to optimize my earnings". Thus what we need in the meantime is the simulation of the best manager intuition with the inclusion of the most possible quantitative analysis and, if possible, ad hoc efficient heuristics. Toward this aim we also need to seek more enterprise-wide straightforward models, for the direct solution of the complete synchronization problem as target

Stories and facts can show the magnitude of the problem related with spreadsheet mistakes when applied in financial issues. Examples are in abundance in the web page of the European Spreadsheet Risks Interest Group (EUSPRIG, http://www.eusprig.org). One mistake discovered by GAO, the office of the generally accepted accountancy principles of USA, was in a subsidy estimate, which error was an incorrect reference formula in one cell of a summary spreadsheet. Titles like "Spreadsheet calculation error: $100,000 overoptimistic revenues" or others –"Mistakes happen during budget planning:US$70M", "NASA misstated by $644M: undetected spreadsheet errors in "ad hoc" process", "Auditors say spreadsheet controls not sufficient" can show the scale of drawback and shortcomings.

As reported in CFO News (www.cfo.com), it is incredible that the technological innovation pace let spreadsheets be the basic CFO tool, while they "take so long that time for analytical work is suppressed". This consuming work time distracts financial staff from higher value analytical activities, provoking the inability to revise forecasts and to have optimal budgets during the required financial period that must be at least monthly. Thus, reality is dark: the average of active budgets per year is one per 93 days in USA, when first cause of enterprise failure is the financial policy. In addition, dramatic changes in the business scenario need a reconfiguration of finance organizations and CFO's role (GAO Office USA Report, 1999) at a more prevalent position and active participation as value producer, strategist, high qualified adviser, analyst and business partner in order to improve the corporate value and hence, its competitive advantages. Thus now, more than ever, CFO needs an appropriate tool to work.

Financial and planning management staff needs a tailor-made version tool to aid the CFOs do its work. Charnes, which first introduced linear programming to the area of finance with Cooper and Miller (1959), already anticipated that due to a number of circumstances the applications were concentrated in the production area, but there was no reason for not applying the same techniques to financial planning, including purchases and product sales, or even more, in joint operating and financial planning. Now we did not find any precedent of Charnes besought approach in joint operative and financial modeling in literature or software market, besides the model described here.

Which are the roots of the problems described above? In our opinion, the entire hierarchical planning process (HPP), summarized in Figure 1a, is out of date. In Figure 1b we propose a forward looking methodology, enhancing the scope of recipes in advanced planning and scheduling (APS) systems, in order to include details of the entire enterprise SC management. It is essential to foster the substitution of the current material logic of HPP and its trial and error procedure (1.a), by the financial logic with simultaneous joint integration (1.b).



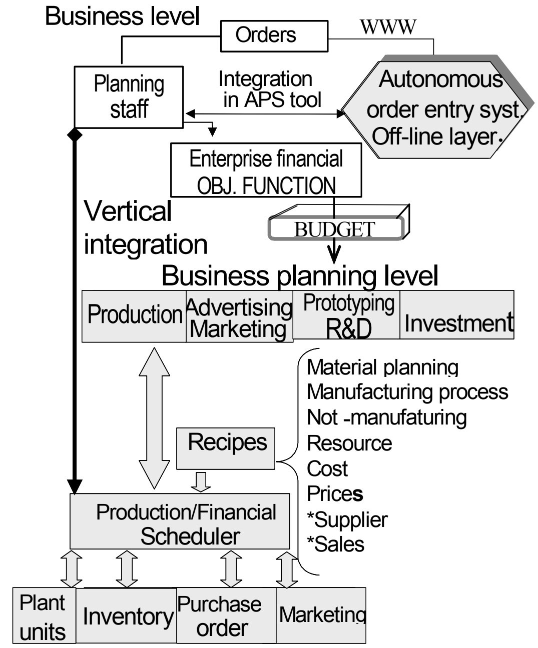


Figure 1a. Current HPP methodology. **Figure 1b. Our proposed methodology.**

2. Previous work & remarks about the core of problem formulation

A review of the previous theoretical works in the literature reveals that budgeting models for financial control emerged earlier than operation schedules. More than 50 years ago Howard & Upton (1953) alerted of an evident gap when they affirmed that cash is the lifeblood of business enterprise and its steady and healthy circulation throughout the entire business operation by an effective control of cash has been shown repeatedly to be basis of the business solvency. This status was successfully reached for other resources (materials, by the material resource planning (MRP) system and successors), but not for money (the most valuable resource).

The facts trajectory in this branch began when an initial sequential approach, focused on individual financing problems, was later developed towards the simultaneous consideration of several financial decisions. This included cash flow management, resources and financing distribution, and the investment of the excess cash in marketable securities (Charnes et al.,1963, Robichek et al., 1965; Orgler, 1969; Srinivasan, 1986). Robichek (1965) considered that the reason for considering isolated subproblems in financial management was that the overall financing problem was too complex to be analized jointly and recognized the simultaneous approach as the only one capable of optimizing financial decisions. Robichek also emphasized that linear programming and financial management were still not mature to let them capture the whole financial problem within a single straightforward treatment. Fortunately, today this situation is different. In our opinion, one added complexity of integrating, not only the financial models, but financial and operative models, is that the financial tasks occur in discrete time while the operative tasks are made in continuous time.

Still an effective cash plan and control is not yet as operative as production and material schedules are. In practice the financial matters are not still integrated on their own to support financial decision making. One of the reasons for the lack of integration is that until now scheduling/planning and budgeting modeling have been treated as separate problems and have been implemented in independent environments. Furthermore, being the optimal production schedules (developed by engineers in computer tools in the batch industry) complex to understand and convincing, CFO has insufficient arguments against that evidences, often falling slave of financial risky production decisions.

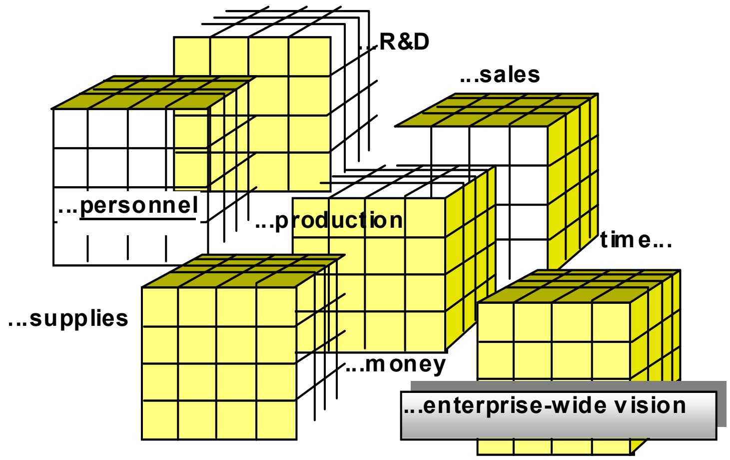


Figure 2. CFO global enterprise oversight.

In reality, the current conditions to work invalidate a proactive management, placing serious difficulties in the performance of the short term budgeting process and supervision. The lack of tools to manage working capital in some way forces CFO to make decisions using overdue or imprecise information because budget supervision is lacking due to the lack of regular budgets: the output time average is already a quarterly emission.

On the operative side, a huge number of models that perform short term scheduling and longer term planning of batch plant production have been developed, especially in the last 25 years, for optimizing quality or cost-related performance measures (Shah, 1998). As commented above, from the beginning the feasibility of operative scheduling and planning models' output was supported by another model, the MRP system, which emerged earlier than production scheduling. Until now both models – schedule and MRP – remain as independent subsystems when discarding unfeasible plans during the hierarchical planning, which is still based on material logic. Since the hierarchical planning requires here a trial and error loop between different departments to evaluate the viability of the proposed plan, e.g., between MRP and the scheduling model, it cannot offer the necessary uphold to an economy that must respond to a financial logic dynamically.

The scientific background of integration was since the beginning, and still is, behind practice. While the scientific background of integration is lacking, the technical practical achievements are exaggerated. This is the case of ERP systems. The systematic deployment of more qualified information will be the key of new enterprise-wide optimization systems. Managers could make better business and technology decisions if they can use accurate simulation tools and timely process data. The generation of prices considering costs limits is needed during the time period where a product is asked and not afterwards. The challenge is to make trade-off solutions with maximum economical performance of the process, while satisfying customers.

With a global enterprise and operational oversight (see Figure 2) CFO can distribute finite resources optimally. A financial & SC simulation tool lets "play" with different alternatives during planning supported with all the information and having absolute transparency of the limitations and interactions occurring at the plant for each alternative tested. With this aid it is possible to keep the visibility/transparency of the cumbersome interactions between batches at the plant floor in multi-site levels and to change the today slave or blind position of business level during planning and decision-making. Raaymakers, et al, 1997, presented data of a real case study in the chemical industry applying HPP, where only the 80-60% of the plans proposed by the superiority were feasible as a result of the lack of knowledge of the interferences between batches at the plant floor. Without this approach the business staff could continue proposing erratic plans at strategic and tactical level with the corresponding failure of the capital budget funds and expectative.

Let's say briefly that the cash management problem consists of optimally financing net outflows through a line of credit, pledging receivable accounts, selling marketable securities or investing the net inflows in marketable securities considering yield and transaction costs. 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) provoking insolvency, first step to bankruptcy.

When coordinating financial and operational plans, a steady financial management is applied and several advantages are obtained. A first one is the advantage of synchronization of the cash flows. When the financial managers evade insolvencies via synchronization of inflows and outflows, the peaks of cash needed are flatten, avoiding urgent requests of funds. Thus the supposed situations of insolvency that would be created if the cash flows were not synchronized imply a saving equal to a potential cost dependent on the funds requested and its urgency. A second advantage is that when the financial revenues are maximized and the costs minimized by an optimized administration, extra revenues can be obtained, whose amount for certain industries can be a noteworthy percent of the overall earnings.

3. The Integrated Model

From the operations research point of view, the engineering problem of considering resource constraints in time-based processes scheduling, still assumes infinite resources for the case of finances. The schedule is generally based on the time-based resource requirements that can be met from defined resource availability while maintaining the process logic. Currently, to the best of our knowledge, in literature no known formal mathematical model exists that considers the interaction between financial resource allocations, process logic and resource availability in its entirety at an enterprise-wide including operative/floor level. If it is needed the scheduling of working capital assignment to the functional areas of the firm, it becomes essential to consider trade-offs between resource allocations and its effects in the whole functionality.

Simulation plays a remarkable role in this type of scheduling. Owing to the increasingly size of the problem involved, a formal mathematical model, especially at scheduling level, is difficult to obtain in a reasonable time. A pragmatic approach uses the process simulation and modeling for accurate/optimum solution due to the fact that simulation in APS tools is the only method to provide a realistic and accepted solution of scheduling and resource distribution. Thus the first step in this research must be the creation of a formal exact optimization straightforward model for a reduced problem scale in order to have a reference that can validate the second step. The second step consists in the creation of a non exact procedure with the capacity to solve practical problems within an acceptable precision in order to include it in an advanced planning and scheduling (APS) and/or agent system tool. In our experience, this methodology works pretty well in practice and could be continuously improved with the aid of heuristics, software logic, geometry, mathematic operations and staff management rules. Professional APS systems and agent-based systems in universities and market are able to schedule thousands of orders in seconds by using direct calculation and/or heuristics. Moreover, APS or agents can verify simultaneously the feasible MRP solutions to the plan proposed. For a simpler timing of a batch, can be used the size of overlapped times between batches. Looking deeper, the operation is refreshed with a possible protagonist: financial operations are included in recipe format as production recipes do. The objective is to make simultaneous schedules of time and value-added instead of the traditional timing in operative schedules.

In addition, the goal is properly combining the advantages of optimization approaches in operational research with the interactive environment to run operation sequences or schedule logic of the processes. Although it may be obvious that limiting any critical resource will have an adverse impact on the firm and may often increase the process duration, measuring such impact and optimizing it without affecting the process logic is possible providing a mechanism to optimize such impact and select the best scheduling solution. It can be demonstrated, in specific cases, that the advantage of a more uniform cash flow far out-weighs a few deviations from the due dates. Without doubt, the overall synchronization and supervision of cash flow is underestimated and investors or enterprises are not protected against illiquidity. Financial integration must be achieved providing the degrees of freedom to change production or financial decisions in order to synchronize cash flows and lever earnings.

In new conditions, production/SC plans could be substituted by budgets when the overall performance has to be followed. The percentage of resources spent from the budget on strategic support activities can be used as an indicator of how well finance and the respective executors, mainly cross-functional process teams, support mission objectives. The practical significance of this work has far reaching economic implications in the chemical batch plant and process industry. Not making budgets declines the deserved leading position of finances when its potential benefits in control and optimization are not consummated. Worse yet is that there is no consciousness of these shortcomings.

However, exact models are the first step in the creation of realistic tools able to pass the test of real time. Unfortunately, mathematical exact solutions have limitations (acceptable for not more than 30 products). Now a comprehensive approach supported by the results of case studies is used to address the very common problem of cash-flow resource constraint in the process industry.

The classical approach decouples the planning and scheduling decisions from budgeting considerations, and decides first on planning and scheduling and then it simply performs the corresponding financial computations for budgeting. As opposed to this approach, here we show that one can obtain significant financial gains by considering both, plan and budget problems, simultaneously.

Additionally to the joint time-money models, the liquidity control is undertaken when cash is retained at a minimum level, searching for options to invest the surplus if an opportunity exists. To formalize the liquidity in the financial model it is recommendable to use the typical financial categories of the balance sheet (Shapiro, 2001), that is, the current assets (CA), fixed assets (FA), current liabilities (CL), long term debt (LD) and equity (E). In Figure 3 are shown the enterprise-wide activities, flows and documents related in the proposed scenario. The mathematical balance equation ($CA + FA - CL - E = 0$) controls the net flows of the firm's cash, making it possible to control the updated liquidity in the integrated functional model. In this joint environment the movements of events related to financial activities (of the SC), that create the monetary flows, are permitted. For this reason, it is feasible to smooth the money peaks reaching optimal synchronization of cash flows. Next we show the results of MILP models of two examples, the first one mainly within an enterprise scope (Romero et al., 2003) and the second one, within a detailed SC scope. The methodology consists in comparing the decoupled models with the integrated ones.

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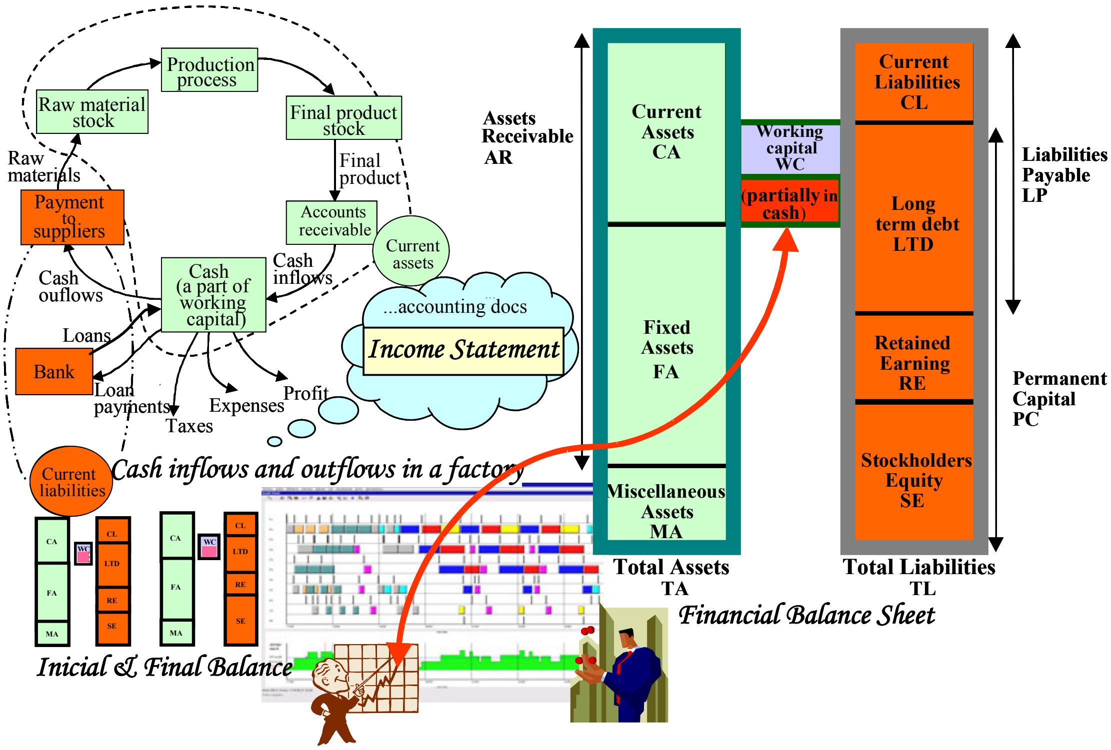

Figure 3. Scheme of the approach proposed to manage cash.

4. Case study I

This first case study consists of a batch specialty chemical plant with two different batch reactors (R1 and R2), excerpted from a real industrial scenario (Romero et al. 2003). 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 trucks to be transported to different customers. Plant product portfolio is around 30 different products using up to 10 different substances. Production times 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 oscillates from 0 up to 6 hours. The objective of the scheduling algorithm, equation (1), is to maximize in a week horizon (168 h) the profit obtained (B_i Y_i) 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) minus the cleaning cost ($CC_{i,i'}$). The problem to solve is a 13-week period. The following equations (1) to (3) show the scheduling and 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 times (cleaning times). This way, the sequence minimizes the overall required cleaning for the first week. For the rest of weeks, sudden demands are just known with one week in advance but as their overall number can be estimated, the model leaves enough idle time as to accommodate these ‘unknowns’. The model is to be rerun every week as forecasts develop into real orders. It will be able to decide when to ask for raw materials, considering an economic order-size.

Operative model

Objective_Function

$$\max \left\{ \sum_i B_i Y_i - \sum_e \sum_k \sum_i \sum_{i'} CC_{i,i'} \ \mathrm{x}_{\mathrm{i,k,e}} x_{i,k-1,e} \right\} \tag{1}$$

where the first term $\sum_i B_i Y_i$ is the sum of gross margins apported by the processed batches, and the second term discounts the cleaning cost CC of the assigned batches. The assignment binary variable of batch i at position k in the sequence at equipment unit e is denoted by $x_{i,k,e}$. This objective function is maximised subject to the following constraints of timing and batch sequence:

$$\begin{aligned} &Schedule\_Ti\min g \\ &TF_{k,e} = TI_{k,e} + \sum_i TOP_i x_{i,k,e} + \sum_i \sum_{i'} CT_{i,i'} \ \mathrm{x}_{\mathrm{i,k,e}} x_{i,k-1,e} \quad k \geq 1 \\ &TF_{k,e} = TI_{k,e} + \sum_i TOP_i x_{i,k,e} \quad k = 1; TI_{\mathrm{k,e}} \geq TF_{k-1,e} \quad k \geq 1; \mathrm{TI}_{\mathrm{k,e}} = 0 \quad k = 1 \end{aligned} \tag{2}$$

$$\begin{aligned} &Batch\_sequencing \\ &\sum_{\mathrm{e}} \sum_k x_{i,k,e} = Y_i \quad ; \sum_i x_{i,k,e} \leq 1 \ ; \quad \sum_i x_{i,k,e} \leq \sum_i x_{i,k-1,e} \quad k \geq 1 \end{aligned} \tag{3}$$

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 $TI_{k,e}$ are, respectively, the ending and initial times of job k in the sequence at equipment unit e. The model that results by introducing aggregated variables for $x_{i,k,e}\, x_{i,k-1,e}$ in model (1)-(3), is a mixed integer linear problem (MILP), that is solved using GAMS-CPLEX. In order to solve the problem in an efficient way: First, we schedule the six products with more hourly contribution to profit and then the remaining products. Although this strategy might not produce the optimal solution to the original problem, it also improves revenues and profit, and it permits to solve the combinatorial explosion problem in less than 20 CPU s at a 1 GHz machine.

Budgeting Model.

Short-term budgeting decisions can be made every week-period. Week production expenses will consider an initial stock of raw material and products. Considering cash variability, the CFO determines the minimum allowed net cash flow. Here, the initial working capital cash is given as minimum, beneath which a short-term loan must be requested

Production liabilities incurred in every week-period are assumed to be due to purchase of raw materials and the sale of products is assumed as one of the exogenous cash-flows. A short term financing source is represented by a constrained open line of credit that requires a minimum safety stock under agreement with banks. Loans can be obtained at the beginning of any period and are due after one year at a monthly interest rate. 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. By introducing the planning and scheduling equations into the budgeting model presented, we obtain the following integrated model for production scheduling and planning, and enterprise budgeting.

$$\mathrm{W}cash_k \geq Min\_Cash \tag{4}$$

$$\mathrm{R}\_Liability_{k-1} = \sum_r qb_r \cdot rb_{r,k} \cdot CostRaw_r \tag{5}$$

$$Exogenous\_cash_k = \sum_{i|D_i=k} satis_i \cdot qp_i \cdot SaleP_i \qquad (6)$$

$$\begin{aligned} & Debt_k \le Max\_debt \\ & Debt_k = Debt_{k-1} + Borrow_k - Out\_Debt_k + F \cdot Debt_{k-1} \end{aligned} \qquad (7)$$

$$\begin{aligned} MS\_net\_cashflow_k = & -\sum_{k'=k+1}^{13} \left(MSinv_{k',k} - MSsale_{k',k} \right) \\ & + \sum_{k'=1}^{k-1} \left(d_{k,k'} MSinv_{k,k'} - e_{k,k'} MSsale_{k,k'} \right) \end{aligned} \qquad (8)$$

The cash balance is as follows,

$$\begin{aligned} & Exogenous\_cash_k - R\_liability_k + Borrow_k - Out\_Debt_k \\ & + MS\_net\_CashFlow_k + WCash_{k-1} + others_k = WCash_k \end{aligned} \qquad (9)$$

For months 4, 8 and 12, cash is withdrawn from the system in form of shareholder dividend. The objective function consists in maximizing these dividends as follows:

$$\begin{aligned} & others_{m=3,6,9,12} = -share\_div_l \quad l = 1,2,3,4 \\ & O.F. = \max \sum_l \alpha_l \cdot share\_div_l \end{aligned} \qquad (10)$$

<u>Comparison of results of sequential and integrated modeling</u>

(a) Decoupled models

The planning model has been run for a plant product portfolio of 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.

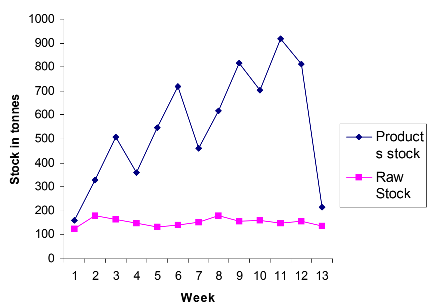

Figure 4. Results of planning model.

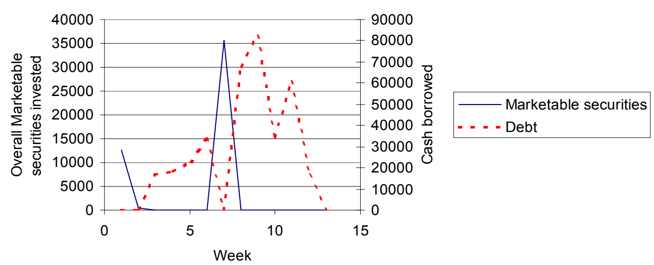

Figure 5. Results of budget model.

The proposed model has been implemented in GAMS/CPLEX and solved at a 1 GHz machine. An optimal solution is obtained in 190 CPU seconds. Figure 4 shows the profile of stock of raw materials and final products over the three months. Figure 5 shows the services of debt used and the investment in marketable securities.

For the budgeting model, it was assumed that i) no marketable securities were invested at the beginning of the period; ii) the initial cash is equal to the minimum cash (20000 m.u.); iii) there is an open line of credit at an annual interest of 10%; and iv) there is a set of marketable securities at 5% annual interest. In the 12-months horizon it is assumed that cash is withdrawn for dividend emission at periods (months) 4, 8 and 12. With this data, we solved the proposed LP problem. The cash withdrawn during all the year is 185,588 m.u.

(b) Integrated model

With the integrated framework the overall cash withdrawn during all the year is of 203.196 u. As shown in Figures 6 and 7 the stocks have a smaller size in the integrated model. Therefore, less debt is obtained, and, also, the debt is obtained later. In addition we also obtain better results regarding the portfolio of marketable securities. This results in a 9,5% more of dividend to shareholders.

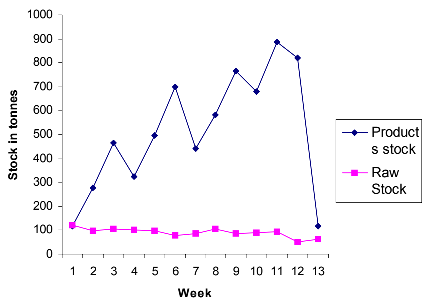

Figure 6. Planning result, integrated model.

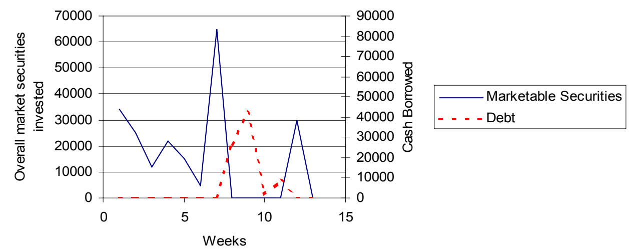

Figure 7. Budget result, integrated model.

5. Case study II

Here, we propose a mathematical formulation to address the integrated planning/scheduling of chemical SCs with embedded multi-purpose batch chemical plants. The model divides the planning and scheduling horizon H into intervals of length H1 where production is planned using known as well as estimated demands which are provided by a forecasting tool. Moreover, the first planning period is divided into intervals of lower length H2 where production is scheduled as depicted in Figure 8. The model is to be rerun every H1 period as forecasts become real orders. Therefore, the results of the planning horizon beyond the first period H1 will never reach execution. However, they are important to be considered when solving the scheduling horizon, because one could schedule in such period the production of materials needed in periods beyond it and keep them as inventory. At the financial side, the reschedule carried out each H1 period provides a reliable forward-looking scenario aiding the synchronized financial decision making and the optimized application of the mid-term financial planning postulates.

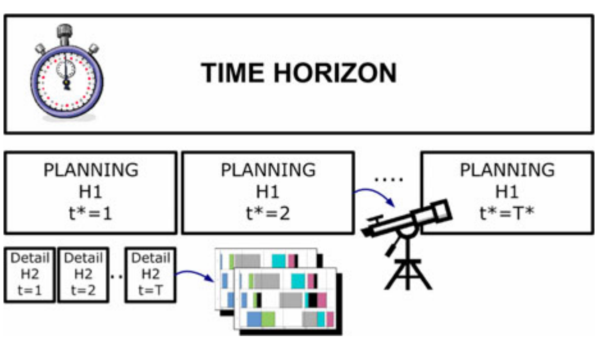

Figure 8. Structure of the model.

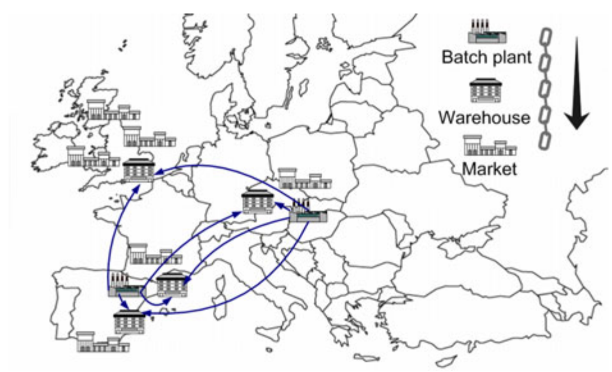

Figure 9. Case Study.

First stage: detailed scheduling

Here, the detailed schedules of the different sites of the SC as well as the transport decisions are optimized. Production demands and raw materials and final product stocks are known. Here, the detailed schedules of the different sites of the SC as well as the transport decisions to be implemented through the nodes are computed. The first time period H1 is divided into t intervals of length H2. The scheduling constraints are based on the discrete STN formulation of Shah et al. (1993), although other either continuous or discrete time scheduling formulations could be easily accommodated within the model. It should be also mentioned at this point, that it is necessary to slightly modify the mass balance constraints proposed by the author for properly modeling the transport of materials through the nodes of the SC.

Second stage: production planning

Here, nor the exact sequence of batches produced neither the initial and finishing times of the involved tasks are calculated within every period, apart from the first one, but estimated by means of an aggregated STN representation based in the work of Maravelias et al. (2004). For each task i, it is defined a maximum number of copies, i.e. an upper bound on the number of batches of task i that can be carried out in any feasible solution. Constraint 11 is a relaxed assignment constraint which enforces that the sum of the durations of the tasks assigned to a unit does not exceed the length of each planning interval (H1). Here, Ij represents the set of tasks that can be assigned to unit j. In this case, it has been assumed constant processing times. The capacity limits for equipments are expressed by equation 12.

$$\sum_{c\in C_i}\sum_{i\in I_j} pt_i \cdot W_{cit} \le H \qquad \forall t \tag{11}$$

$$0 \le B_{cit} \le B_i^{MAX} \cdot W_{cit} \qquad \forall c \in C_i, i, t \tag{12}$$

The amount of state s at the end of the time interval t is calculated through constraint 13 in which it is forced to be equal to the initial amount plus the amount produced and purchased and minus the amount consumed and sold during t. Therefore, only assignment (11), batch size (12) and mass balance constraints (13) are included.

$$S_{st} = S_{st-1} + \sum_{c\in C_i}\sum_{i\in SO_s} B^O_{cist} + \sum_e Purch^{RM}_{et} - \sum_{c\in C_i}\sum_{i\in SI_s} B^I_{cist} - Sales_{st} \quad \forall s,t \tag{13}$$

Concerning financial matters, it should be mentioned that the cash-management constraints applied in this work have been taken from Romero et al. (2003) and consider transactions of cash due to buys or sales of marketable securities, sales of final products, payment of liabilities, the use of short-term financing sources and pledging. Nevertheless, in our formulation the change in equity achieved by the enterprise (ΔEquity) for a given horizon of time, and not the cash withdrawn from the company as dividends, is pursued as objective aiming at the direct enhancement of the value of shareholder's interest (SHV) in the firm, which seems to be today's priority. This term can be computed as the net different between the change in assets, which include both, the current assets (CA) and the fixed ones (FA), and the change in liabilities, comprising the current liabilities (CL) and the long-term ones (L). To achieve the integration between operative and financial decisions, the production liabilities and exogenous cash at every week-period are calculated as a function of production planning variables. That is, the inflows of cash are determined from the sales of products assuming a known delay between the execution of the purchase and the corresponding payment, while the amount of raw materials and utilities purchased to the external suppliers are computed from the operative variables of the aggregated STN:

$$Purch_{et}^{TOTAL} = \sum_{c \in C_i} \sum_{i \in USup_e} \sum_{t} W_{cit} \cdot \alpha_{ie} + B_{cit} \cdot \beta_{ie} + \\ + \sum_{s \in RMSup_e} Purch_{est}^{RM} \gamma_{se} \cdot g_{est} \qquad \forall s,t \tag{14}$$

It should be pointed out that the above presented model can be hierarchically-decomposed into two levels, a master planning problem and a scheduling one. This would lead to more tractable problems thus decreasing the required computational effort. However this is out of the scope of this work, which is focused on the effect of incorporating financial issues into planning/scheduling models rather than developing the best solution strategy for the resulting problem.

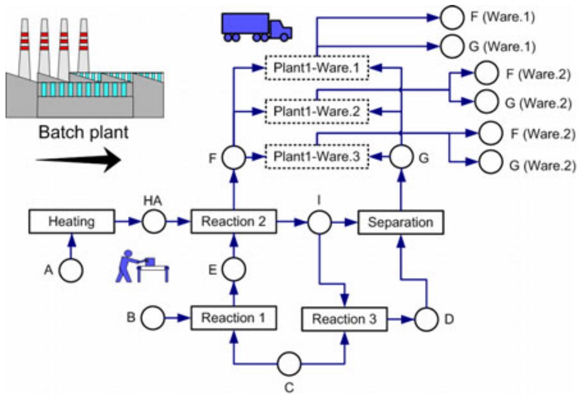

Figure 10. STN representation of the case study (I).

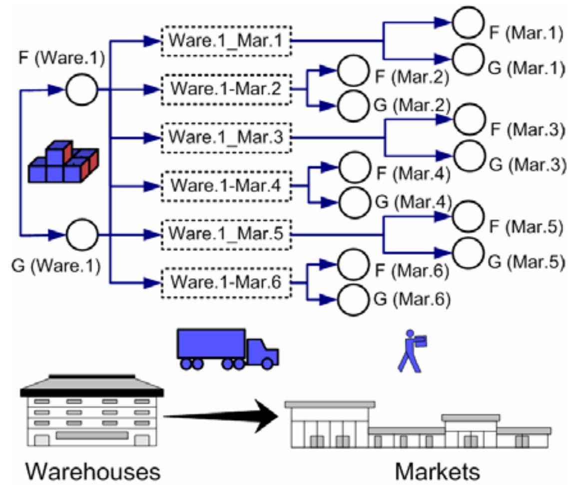

Figure 11. STN representation of the case study (II).

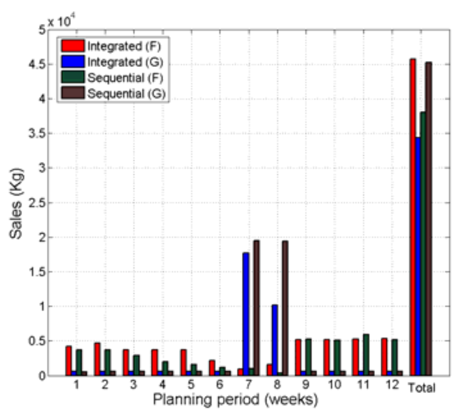

Figure 12. Sales.

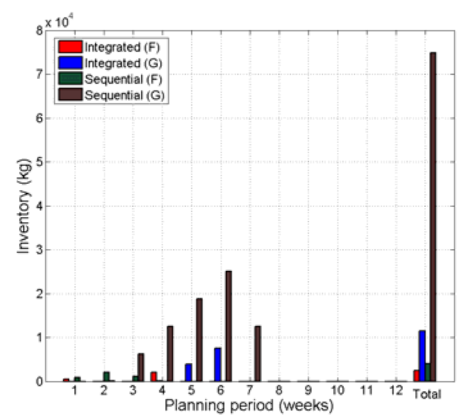

Figure 13. Inventories.

The proposed approach is applied to a case study. The structure of the SC under study is given in Figure 9, while Figures 10 and 11 depict the STN representation of the resulting network, which comprises two multipurpose batch plants, three warehouses and six markets. Twelve planning intervals with a length of one week are considered. The scheduling formulation considers a time horizon of one week divided into 60 intervals of 2 hours each. The structure of the multipurpose batch plants is taken from the case study proposed by Kondili et al., (1993). To highlight the advantages of our integrated approach, a two-step sequential scheduling-planning and budgeting approach is also applied. This situation corresponds to a typical nowadays optimized industrial routine where first operations are decided to then try to fit the finances.

The implementation in GAMS of the planning model consists of 38203 single equations, 38203 continuous variables, and 6839 discrete variables. It takes 544 CPU seconds to reach a solution with a 0 % integrality gap on a AMD Athlon 3000 computer using the MIP solver of CPLEX (7.0). Once the scheduling-planning model is solved, the budgeting model is optimized. This model has 448 single equations and 664 continuous variables. It is solved in 0.062 CPU seconds. On the other hand, the integrated model leads to 342485 single equations, 38866 continuous variables, 6839 discrete variables and 1040 CPU seconds to reach a solution with a 0 % integrality gap on the same computer.

The sales and the inventories associated to the production plans computed by each of the solutions are given in Figures 12 and 13. The financial Gantt charts associated to these solutions, in which all the outputs and inputs of cash are detailed, are shown in Figures 14 and 15. As it can be observed, the solution achieved with the integrated model incurs in less debt and pledges less accounts receivable than the sequential one. The change in equity achieved with the integrated approach is 30 % higher than the sequential one (3.576.209 m.u. for the integrated model and 2.488.312 for the sequential approach). It should be pointed out, that the case study presented here is a very specific situation where there is one product with a very high profitability in comparison with the others. Such item has a high price and consumes an expensive raw material. Given this data, the planning-scheduling model decides to fulfill the demand of this material as much as possible, what makes the budgeting model pledge receivables for purchasing the necessary raw materials. On the other hand, the integrated approach leads to lower production rates of this material, as it is capable of properly asses the financial impact derived from the operative decisions.

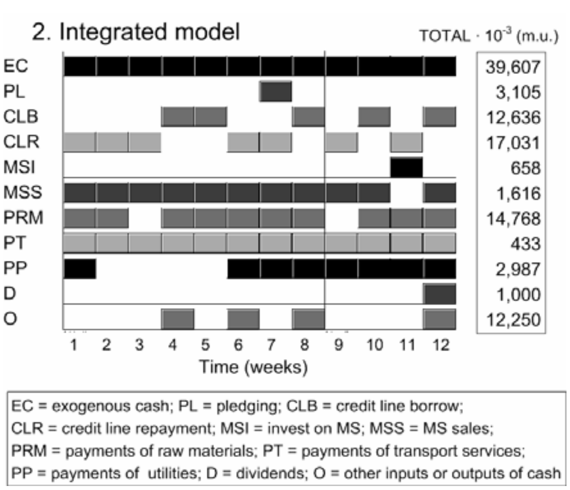

Figure 14. Financial Gantt Chart (sequential approach).

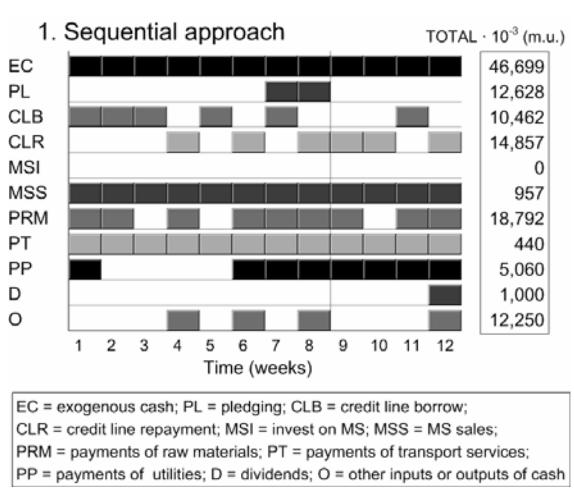

Figure 15. Financial Gantt Chart (integrated model).

5. Conclusions

The concept behind improved SC planning systems is the overall integration of the whole enterprise functionality through financial links (Pekny & Reklaitis, 1998). And this is true: the informative, functional, spatial and intertemporal integration is a besought dream and challenge since many years. The synergy between corporate financial and SC management integration has not been exploited up to now. Even though these advantages of joint functional integration have not been evaluated, there is a positive consensus in literature regarding this advance. In this work is created an innovative computational tool that permits to apply complex models in industrial practice. Besides the decrease of costs or increment of revenues and the benefits of cash flow synchronization by load rearrangement to flatten peaks balancing firm's liquidity, there is an internal benefit in companies that rarely is possible to be measured with something else than intuitive reasoning. It is the opportunity cost ignored by not optimizing the quality of management decisions, and very especially in the resource assignment to functional areas that create value. When the enterprise is endowed with up to the minute information about the overall budget status, demands, costs, schedules, allocation of resources, reschedules and cost of capital, then the enterprise is ready to respond efficiently to events as they arise, with full knowledge of the treasury expenditures and knowing which are optimal decisions. Unfortunately, many times the firm's high level staff agrees that there is not enough time to change a general methodology, having always plenty time to continue using the current insuffucient modus operandus. Poor objective functions and poor management are not convertible into valuable by the mere substitution of the measuring rule or the objective function. What is required is a management change improving practices, synchronizing the resources and best actions and measuring a priori what will be done to add value to the corporation and its stocks. Thus, taking into account that the financial management is the first cause of enterprise failing, a software like the one exposed here should be a valuable contribution to enterprises, and consequently to economy.

6. Notation

Case study I

Bi	Gross margin (*price – total cost*) of a batch of product *i*
Yi	Number of batches *i* assigned to a sequence position *k* in unit *e*
$CC_{k,e}$	Cleaning cost after sequence position *k* at equipment unit *e*
$TF_{k,e}$, $TI_{k,e}$	Final and initial time of sequence position *k* at the equipment unit *e*
$X_{i,k,e}$	Binary assignment variable of product *i* to position *k* in unit *e*
TOP_i	Processing time required for producing product *i*.
$Wcash_k$	Cash at period *k*
Min_Cash	Safety stock of minimum cash
$R\_Liability_k$	Production liabilities due to buys of raw materials at period *k*
qb_r	Amount of raw material *r* per lot purchased
$rb_{r,k}$	Number of lots of raw material *r* being received at period *k*
$CostRaw_r$	Unitary cost of raw material *r*

$Exog\_cash_k$	Exogenous cash from product sales, assets & pledging at period k
$satisf_i$	Binary variable determining if an order i will be accepted/fulfilled.
qp_i	Amount in tons to be delivered in the order i
$SaleP_i$	Sale price per unit of order i
$Debt_k$	Actual debt incurred by the firm at period k
Max_Debt	Max debt in agreement with a bank (limited by Min_Cash)
$Borrow_k$	Amount of capital borrowed in period k
F	Interest rate of credit obtained beginning a period, due after 1 year
Out_Debt_k	Amount of the credit line repaid at period k
$MSinv_{k,k'}$	Is the cash invested at period k maturing at period k'
$MSsale_{k,k'}$	Is the security sold at period k maturing at period k'.
$d_{k,k'}$, $e_{k,k'}$	Coefficients defining the yield of marketable securities
$MS\_net\_cashflow_k$	Cash flow from sales and purchases of securities at period k
$others_l$	Other expenditures as shareholder dividends during l months
α_l	Weight coefficient for shareholder dividend payment at l months
$\mathrm{share\_div}_l$	Shareholder dividends in month l

Case study II

α_{ie}	cost fraction of i payable to e
β_{ie}	cost fraction of i payable to e
B_{cit}	batch size of c of i in t
B^I_{cist}	amount of s consumed by c of i in t
B^{MAX}_i	maximum batch size of i
B^O_{cist}	amount of s produced by c of i in t c copies
C_i	set of copies of i

e	external suppliers
γ_{se}	fraction of *s* purchased to *e*
t	planning periods
g_{est}	price of *s* offered by *e* in *t*
H	planning period length
i	tasks
I_j	set of *j* equipments available for task *i*
j	equipments
pt_i	processing time of *i*
$Purch^{RM}_{est}$	amount of *s* purchased to *e* in *t*
$Purch^{TOTAL}_{et}$	total purchases payable to *e* in *t*
$RMSup_e$	set of raw materials provided by *e*
S_{st}	amount of *s* in *t*
$Sales_{st}$	sales of *s* in *t*
SI_s	set of states outputs of task *i*
SO_s	set of states input to task *i*
$USup_e$	set of utilities provided by *e*
W_{cit}	binary variable (1 if *c* of *i* is performed in *t*, 0 otherwise)

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