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Integrating process operations and finances for the optimal design of chemical supply chains

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Abstract

The tight profit margins under which the Chemical Process Industry (CPI) operates are forcing companies to pay more and more attention to the design and operation of their Supply Chains (SC). Traditional approaches available in the Process Systems Engineering (PSE) literature to address the design and operation of chemical SC focus on the process operations side and neglect the financial part of the problem. This work deals with the design and retrofit of chemical SC and proposes a novel framework that consists in the inclusion of financial considerations at the strategic decision-making level. Within this framework, decisions that have a long-lasting effect on the firm are assessed through integrated models which are capable of holistically optimising the combined effects of process operations and finances. The main advantages of the proposed holistic approach are highlighted through a case study, in which the integrated approach is compared with the traditional myopic method that pursues a fairly simple performance indicator as objective and neglect the financial variables and constraints of the problem. The integrated solution not only ensures the feasibility of the strategic decisions from the financial viewpoint but also leads to superior performance in terms of value measures.

Keywords

Supply chain design, corporate financial planning, and optimisation.

1. Introduction

This work focuses on the strategic level of the Supply Chain Management (SCM) problem. In simple terms, the SC design problem involves the identification of the combination of suppliers, producers, and distributors able to provide the right mix and quantity of products and services to customers in an efficient way[1]. The main novelty of this work lies in the inclusion of: 1) financial considerations at the strategic decision making level and 2) a corporate value performance indicator.

2. Problem Statement and background

Recent advances in PSE have focused on devising enterprise wide modelling and optimisation strategies that integrate decisions of distinct functions of a business into a global model. Nevertheless, almost all of the models developed to date focus on the process operations side and neglect the financial variables and constraints associated with cash flows. Moreover, assessing the feasibility of the design/planning decisions from a financial viewpoint may not be enough for companies that want to achieve a competitive advantage in the marketplace. Fierce competition in today's global markets is forcing companies to perform further analyses in order to find the best production-distribution decisions to be carried out in their SC. If they wish to remain competitive, it is essential to properly assess the different process operations alternatives in terms of their ability to markedly improve the value of the company. Managers should extend their analysis to include the more general objective of maximising the value of the firm as opposed to the common optimisation of traditional biased key performance indicators (KPI) such as cost or profit.
The authors consider that companies can create more value and achieve better performance by devising integrated approaches for SCM. There is an increasing awareness of the impact that chemical process production systems have on firms' finances, which has led to enterprise-wide management strategies that aim to provide a holistic view of the system. Thus, with the recent advances in optimisation theory and software applications there is no apparent reason why models for SCM that merge concepts from diverse areas cannot be constructed.

3. Paper approach

A general framework for the design of SC based on the development of models which cover both areas of the company, the process operations and the finances is proposed. To achieve this goal a deterministic mathematical formulation which utilises mixed integer modelling techniques and merges variables and constrains belonging to each of the above commented disciplines is derived and applied to a case study. The strategy considers the financial performance as a design objective. Corporate value (CV) is adopted as the objective to be maximised as an alternative to the commonly used profit or NPV. In order to assess the trade-off between these objectives a multi-objective model has been developed.

3.1. Mathematical Formulation

The mathematical formulation derived to address the aforementioned problem is next described briefly. The variables and constraints of the model can be roughly classified into two groups. The first one concerns the process operations constraints given by the supply chain topology. The second one deals with the financial area. Finally, the objective function formulation is explained. The structure of the SC taken as reference to develop the mathematical model is illustrated in figure 1.

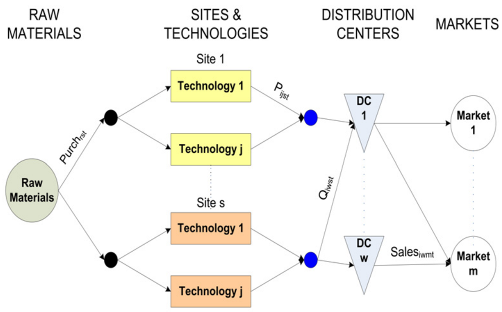

Figure 1: Supply chain model structure

3.1.1. Design-planning formulation

The design-planning formulation is based on the work developed by Hugo and Pistikopoulos[2]. This model has been enhanced to allow the storage of products and to include distribution centres (DC) nodes in the SC network.

3.1.2. Cash management formulation

The cash management associated with the operation of the SC is analysed by extending the mathematical formulation developed by Guillén et al.[3]. Such formulation is thus connected to the production and distribution of facilities through the periods and sizes of purchases of raw materials and utilities to suppliers and the sales of final products to customers. Therefore, payments to providers, short and long term borrowing, pledging decisions, the buying/selling of securities, fixed assets acquisition, quantity discount policies, are planned in conjunction with manufacturing and distribution tasks. The financial side of the problem is then tackled through the inclusion of a set of constraints that accommodate the aforementioned economical issues.

3.1.3. Objective function

In this work the discounted-free-cash-flow method (DFCF) is applied to assess the strategic SC decisions. According to Weissenrieder[4], the company's market value is a function of four factors: 1) investment, 2) cash flows, 3) economic life and 4) cost of capital. DFCF method has become the most preferred approach for the valuation of companies given its capacity for properly assessing these factors. Next, it is explained each component of this method.

Free cash flow. Cash flow at every period t (FCF_t) derives from a function that depends on net operating profit after taxes, change in net working capital (ΔNWC_t) and net change in investments ($NetInvest_t$). This can be seen in Eq (1). It is very important to point out that there will be value generation if the incoming value ($Profit_t(1 - trate)$) is greater than the consumed value (ΔNWC_t + $NetInvest_t$).

$$FCF_t = Profit_t\left(1 - trate\right) - \left(\Delta NWC_t \; + \; NetInvest_t\right) \qquad \forall t \qquad (1)$$

Regarding the change in net working capital needed in each period *t* (NWC_t), it is related to current assets and liabilities and can be seen as the investment required to convert raw materials into finished goods, and finished goods into sales. Change in net working capital is assessed as the change in accounts receivables, plus change in inventory, minus change in accounts payable, plus any other financial expenses or incomes (FEx_t), as shown in Eq. (2). Other financial expenses and incomes due to the SC operations include pledging costs, discounts due to prompt payment to suppliers, earnings and expenses due to marketable securities transactions.

$$\Delta NWC_t = \Delta A\mathrm{Re}c_t + \Delta Inv_t - \Delta APay_t + FEx_t \qquad \forall t \qquad (2)$$

Net investment is computed as monetary value of fixed assets acquired in period *t* minus depreciation corresponding to that period.

Discount rate - cost of capital. To compute the DFCF it is necessary to discount free cash flows at a rate equivalent to the cost of capital. The cost of capital should reflect the time value of money and also investment's risk. In this work, the cost of capital is calculated by using the weighted average method (WACC).

Corporate value. Enterprise market value of a firm is given by the difference between the discounted stream of future cash flows during the planning horizon and the net total debt at the end planning horizon (*T*), as shown in Eq. (3).

$$CV = \sum_{t=0}^{T} \frac{FCF_t}{\left(1 + WACC_t\right)^t} - NetDebt_T \qquad (3)$$

The final net debt ($NetDebt_T$) is short and long term credit lines minus cash available at final planning period *T*.

3.2. Case study

The capabilities of the proposed approach are highlighted by solving a retrofitting problem of a SC comprising several manufacturing sites, DC and markets. A set of potential technologies are assumed to be available in the manufacturing sites. Three potential locations for the manufacturing sites and the DC, from which the products should be transported to the final markets, are also considered. These plants can manufacture three different products (P1, P2 and P3) with four different technologies (TA to TD). These final products must be transported to the DC prior to being sent to the final markets (M1 to M5), where they become available to customers. It is assumed an existing installed capacity of TA in S1 and S3. Sixty one planning periods with a length of one month each are considered. The implementation in GAMS of the integrated model leads to a MILP model with 40.306 equations, 46.916 continuous variables, and 252 discrete variables.

3.3. Results & discussions

Numerical results show that the solutions computed by maximising profit or NPV as single objectives are far away from the optimal corporate value. Certainly, the corporate value computed when maximising profit correspond to a 25% of the maximum corporate value solution and when maximising NPV to a 27% (see table 1). An improvement in the profit or NPV is only possible if the decision-maker is willing to compromise the corporate value of the firm. SC configurations with better profits or NPV can only be achieved at the expense of a reduction in the corporate value of the firm (see figure 2). The case study represents a specific situation where there is one market (M2) which pays better prices than the other ones (1.7 % higher). At such market, accounts receivable are due within a larger time period. Under this conditions, the design-planning model that accounts for the maximisation of a myopic KPI decides to configure a SC network capable of easily fulfilling the demand of market M2 as much as possible (see figure 3). The profit and the NPV are indeed blind KPI in the

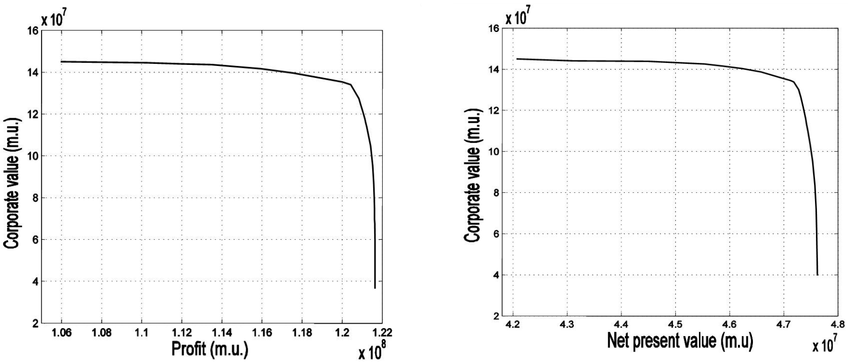

Figure 2: CV – Profit and CV – NPV Pareto curves

sense that they are not capable of properly assessing the financial penalty associated with the increment on net working capital.

SC network configuration	Performance indicator (m.u.)		
	Profit	NPV	CV
Optimum profit	121,653,714.87	47,476,865.35	36,392,463.16
Optimum NPV	121,464,749.10	47,623,655.11	39,557,152.26
Optimum CV	105,955,397.81	42,068,183.09	145,023,155.58

Table 1. Performance indicators for each optimal SC network configuration

4. Conclusions and future work

The framework suggested ensures the feasibility of strategic decisions from the financial viewpoint and also leads to a superior economic performance given its capacity of assessing firm's value creation. This work is thus in consonance with trends in PSE, which is going towards an enterprise wide modelling framework that aims to integrate all the functional decisions into a global model that should optimise an overall KPI. Future work will be focused on taking into account uncertainty into functional integrated models.

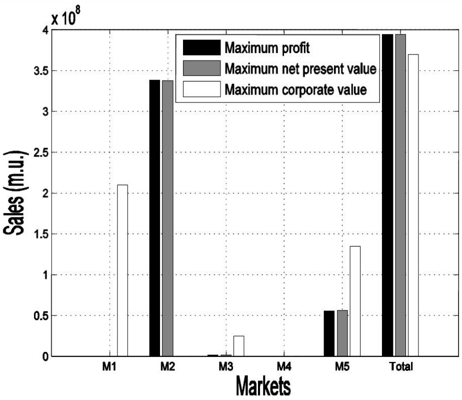

Figure 3: Sales carried out in each market for each optimal SC network configuration

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