Computers & Industrial Engineering 99 (2016) 137–152

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A robust optimization approach for cash flow management in stationery companies

Giovanni Margarido Righetto [a], Reinaldo Morabito [a,*], Douglas Alem [b]

[a] Universidade Federal de São Carlos, Production Engineering Department, Rodovia Washington Luís (SP-310), Km 235, São Carlos, SP 13565-905, Brazil
[b] Universidade Federal de São Carlos, Production Engineering Department, Rodovia João Leme dos Santos (SP-264), Km 110, Sorocaba, SP 18052-780, Brazil

ARTICLE INFO

Article history:
Received 25 May 2016
Received in revised form 8 July 2016
Accepted 9 July 2016
Available online 12 July 2016

Keywords:
Cash flow management
Mixed integer programming
Robust optimization
Network flow model
Stationery industry

ABSTRACT

This paper proposes an effective optimization approach based on mixed integer linear programming and robust optimization to support decisions in the cash management problem of stationery companies. The approach represents the problem by means of network flows with gains and losses in an environment with uncertainty in the parameters that define financial flows over time. A case study was conducted in the cash flow of a typical company in the stationery sector with different grace periods and piecewise linear yields. Several results and analysis are presented by applying this robust optimization approach to support the decision maker in relation to the trade-off between risk and return, showing that the approach is able to generate solutions as good as, or better than, the ones of the treasury of the stationery company. It is in these conditions of uncertainty that the motivation of this research can be found, addressing how financial managers project their cash flows in order to maximize their uncertain monetary resources in a given multi-period and finite planning horizon.

1. Introduction

Cash flow management deals with the efficient use of the net assets of a company. In financial management, tactical planning of the cash flow is a critical activity performed to maximize available resources and minimize financial costs resulting from third-party resource requirements when necessary. Companies pay particular attention to cash surpluses and deficits as they can invest their funds in marketable securities, or raise funds by loans in case of cash deficits (Gitman & Chad, 2014). In addition, cash management should determine the rules for the control of the cash balance while managing a set of factors that are structured in time, such as seasonality effects, specific payments, among others (Brigham & Houston, 2004; Gitman & Chad, 2014).

Due to its importance, the field of cash flow management has been researched in-depth over the past decades. One of the first attempts to fit a mathematical model to a class of cash flow problem was made by Baumol (1952). Since then, academics and practitioners have successfully used operations research techniques in cash flow management and financial engineering, as in Srinivasan (1974), who formulated a transshipment model to minimize the total cost of allocating sources of funds to different uses while retaining the possibility of transferring cash between sources. Gregory (1976) developed models designed to answer questions concerned with the efficient use of the company's cash and short-term investments. Ashford, Berry, and Dyson (1988) reviewed the use of Operational Research in financial management and its application to both short term problems of cash management and long term problems of capital investment. Mulvey and Vladimirou (1992) presented various financial planning problems as dynamic generalized network models with stochastic parameters. Steuer and Na (2003) provided a categorized bibliography on using multiple criteria decision making techniques for problems and issues in finance.

Geunes and Pardalos (2003) discussed the extent to which network optimization approaches have contributed to the advancement of supply chain management and financial engineering research by examining past literature involving network optimization applications within these fields that are still emerging. Gupta and Dutta (2011) studied the flow of money in a supply chain from the viewpoint of a supply chain partner who receives money from downstream partners and makes payments to the upstream partners. Pacheco and Morabito (2011) applied network flow models with gains and losses to deal with the cash flow management problem of a typical Brazilian company, which produces frozen concentrated orange juice. The aim is to maximize the cash return of the financial resources at the end of a multi-period and finite planning

* Corresponding author.
E-mail addresses: giovannirighetto@hotmail.com (G.M. Righetto), morabito@ufscar.br (R. Morabito), douglas@ufscar.br (D. Alem).

http://dx.doi.org/10.1016/j.cie.2016.07.010
0360-8352/

horizon. Alimardani (2014) presented a multi-period financial model proposed on the basis of the network flow structure with many planning advantages. This approach comprises two main steps: dynamic portfolio selection, and dynamic portfolio monitoring and rebalancing throughout the investment horizon.

By optimizing financial processes, the similarity with network flows is natural, as cash flow systems are interrelated and they present numerous parameters with complex relationships (Crum, Klingman, & Travis, 1979; Geunes & Pardalos, 2003). In particular, cash flow management models can be formulated as generalized networks, as the flows on the network arcs may have gains or losses (Crum et al., 1979; Golden et al., 1979; Mcbride & O'leary, 1997; Srinivasan & Kim, 1986). The solutions of these formulations provide (i) less needs for financing investments, in turn, therefore reducing their financial expenses and maximizing their income from financial investments and (ii) an improvement in the process of optimizing cash management, generating optimal strategies for financial managers to scale the flow of monetary resources (Mulvey & Vladimirou, 1992).

The importance of addressing uncertainty in cash flow management problems is also well recognized in the specialized literature (Bensoussan, Chutani, & Sethi 2009; Gitman & Chad, 2014). In fact, one of the main challenges faced by financial managers is to establish policies that make effective operations involving foreign exchange transactions, which are usually based on exchange rate forecasts with inherent uncertain values (Famá & Chaia, 2001; Perdomo & Botelho, 2007). Such uncertainty is one of the main risk factors in the international market, as the fluctuations in the exchange rate may generate significant variations in financial investments. In Brazil, as the historical exchange rate volatility is one of the world's largest and the Brazilian currency is not convertible, companies all over the country that operate in foreign markets, such as stationery companies, suffer from excessive volatility in their cash flows, which affects both cash inflow and outflow made abroad.

Another important source of uncertainty that arises in the cash flow management of stationery and other companies is the interest rate. As highlighted by Garcia and Didier (2003), the interest rate is one of the most important macroeconomic variables, as it influences the level of activity, employment levels, the exchange rate and inflation, among other macroeconomic measures. In Brazil and other countries with a high volatility of interest rates, the volatility significantly affects the interest payments and investment revenues, which in turn affects the cash flow multipliers of these companies.

In this context, the contribution of this paper is threefold: (i) to develop an effective optimization approach based on mixed integer programming (MIP) to support tactical decisions in a cash management problem considering grace periods for investments and piecewise linear yields depending on the amount invested; (ii) to extend the deterministic model to address the uncertainties of the parameters of the problem – cash inflow and outflow and the interest rate for both investment alternatives and bank loans, and (iii) to analyze the application of this approach considering a practical cash flow problem of a typical stationery company. The motivation in applying robust optimization is to avoid more complex (and/or intractable) formulations in comparison to stochastic-based models and to obtain feasible (and near optimal) solutions for any variation of uncertainty parameters within a given interval.

The nominal MIP model that serves as a base for the robust optimization counterpart is an extension of the network flow formulation developed by Golden, Liberatore, and Lieberman (1979). This extension considers bank loans and a set of extra arcs representing financial investments in assets with two or more grace periods and piecewise linear yields, while considering the uncertainty of the problem parameters over time. Companies usually invest their funds in financial assets with different grace periods to receive a higher yield compared with assets that have no grace period for redemption. To the best of our knowledge, this is the first study that develops and applies robust discrete optimization and network flow techniques in cash flow management in this line of research. In general, the aforementioned uncertainty sources have been tackled either via deterministic or stochastic programming models, as pointed out by Mulvey and Vladimirou (1992), Liu et al. (2003), Pacheco and Morabito (2011), Alimardani (2014) and the references therein.

The remainder of this paper is organized as follows. Section 2 presents the extended deterministic MIP model to consider the cash flow problem with grace periods and piecewise yields for the stationery company studied for this research. This formulation also models the cash flow problem of other companies with similar cash flow managements. Section 3 develops a robust optimization approach based on Bertsimas and Sim (2003, 2004) for this cash management problem. The results and analysis of the case study are shown in Section 4. Concluding remarks and future research are discussed in Section 5.

2. A MIP model for the cash flow problem with grace periods and piecewise yields

Similarly to the cash flow problems in Golden et al. (1979) and Pacheco and Morabito (2011), the present cash flow problem considers several assets of different levels of liquidity, with possible conversions between them, and it takes into account various time periods. Fig. 1 presents an illustrative cash flow example considering a planning horizon of n time periods and three assets: a, b and c. Asset a is used for transactional reasons such as money, while assets b and c are financial investments easily converted into cash, but it is assumed to be more liquid than asset b, which in turn is assumed to be more liquid than asset c, and cash disbursements are made only with asset a, since only this asset is accepted as a means of exchange. The initial balances of assets a, b and c are known and it is supposed that all transactions occur at the beginning of each time period (e.g. conversions between assets a and b or c are considered instantaneous at the beginning of each period) and their returns are available at the end of each period.

This cash flow network problem can be represented by graph $G = (N, A, W)$, where N is the set of nodes, A is the set of arcs connecting two nodes in N and $W = [w_{ij}]$ is the matrix of multipliers for each arc (i,j) in A, as depicted in Fig. 1 with the set of nodes $N = \{s, d, z, 1, 2, \ldots, n, \bar{1}, \bar{2}, \ldots, \bar{n}, \bar{\bar{1}}, \bar{\bar{2}}, \ldots, \bar{\bar{n}}\}$. The nodes s and d represent the supply (origin or accounts receivable) and the demand (terminal or accounts payable) nodes, respectively. Nodes 1 to n of the graph correspond to the cash nodes of the company (asset a) in periods $t = 1$ to n, respectively (in the figure, periods $t = i$ to $i+2$). For instance, the vertical arc between nodes s and i (between nodes i and d) in Fig. 1 represents the financial inflow (outflow) to the cash of the company in period $t = i$, while the horizontal arc between nodes i and $i+1$ corresponds to the cash flow of the company from period $t = i$ to $i+1$. Nodes $\bar{1}$ to $\bar{n}$ and nodes $\bar{\bar{1}}$ to $\bar{\bar{n}}$ of the graph correspond to two investment options: without grace periods (asset b) and with two grace periods (asset c) in periods $t = 1$ to n, respectively (note the diagonal arcs between nodes i and $\bar{\bar{i}}+2$, nodes $i+1$ and $\bar{\bar{i}}+3$, and so on, between two periods). The horizontal reverse arcs $(i+1, i)$ are the bank loans, while the horizontal arcs $(i, i+1)$, for $i = 1, 2, \ldots, n-1$; $(\bar{i}, \bar{i}+1)$ for $\bar{i} = \bar{1}, \bar{2}, \ldots, \bar{n}-1$; and $(\bar{\bar{i}}, \bar{\bar{i}}+1)$ for $\bar{\bar{i}} = \bar{\bar{1}}, \bar{\bar{2}}, \ldots, \bar{\bar{n}}-1$, indicate the investments flows of the funds for each asset and period. Note that the horizontal arcs $(\bar{\bar{i}}, \bar{\bar{i}}+1)$ for $\bar{\bar{i}} = \bar{\bar{1}}, \bar{\bar{2}}, \ldots, \bar{\bar{n}}-1$ and the diagonal arcs $(i, \bar{\bar{i}}+2)$ for $i = 1, 2, \ldots, n-2$ represent investment flows in