HAL
open science

A finance driven supply chain network design model

Hamidreza Rezaei, Nathalie Bostel, Vincent Hovelaque, Olivier Péton

To cite this version:

Hamidreza Rezaei, Nathalie Bostel, Vincent Hovelaque, Olivier Péton. A finance driven supply chain network design model. MOSIM 2020 : 13th International Conference on Modeling, Optimization and Simulation, Nov 2020, Agadir (virtuel), Morocco. hal-03176359

HAL Id: hal-03176359

https://hal.science/hal-03176359v1

Submitted on 22 Mar 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

13th *International Conference on Modeling, Optimization and Simuation* - MOSIM*'20 - November 12-14, 2020*
Agadir - Morocco "New advances and challenges for sustainable and smart industries"

A FINANCE DRIVEN SUPPLY CHAIN NETWORK DESIGN MODEL

Hamidreza REZAEI[1,2], Nathalie BOSTEL[3,2], Vincent HOVELAQUE[4], Olivier PÉTON[1,2]

[1] IMT Atlantique, 4 rue Alfred Kastler, Nantes, France
[2] LS2N, UMR CNRS 6004, Nantes, France
[3] Université de Nantes, Nantes, France
[4] Univ-Rennes, CNRS, CREM - UMR 6211, F-35000 Rennes, France
hamidreza.rezaei@imt-atlantique.fr, nathalie.bostel@univ-nantes.fr,
vincent.hovelaque@univ-rennes1.fr, olivier.peton@imt-atlantique.fr

ABSTRACT: *We propose a supply chain network design model focusing on the interactions between logistic and financial considerations. From the logistic point of view, this model determines the optimal location of production facilities and the assignment of these facilities to customers. From the financial point of view, it plans logistics decisions such that a financial indicator is maximized. We propose to use the Adjusted Present Value (APV) as the objective function.*

KEYWORDS: *Supply chain, network design, facility location, finance, Adjusted Present Value, Z-score*

1 INTRODUCTION

Supply Chain Network Design (SCND) aims at optimizing strategic decisions such as "where" and "when" to locate facilities. It also determines the capacity of facilities and product flows in logistics networks. The primary goal in classical SCND models is to maximize the profit or, equivalently, to cut logistics costs.

In this paper we focus on the interactions between the logistic and financial considerations in SCND. At least two financial impacts must be studied. The first one concerns the funding of logistics decisions. There are several means to finance big investment over a long term horizon. This funding may use internal financial resources that the company accumulated prior to the investment. In this case, the investment decision must be anticipated. It can also be financed by borrowing. These two funding levers modify the financial structure of the company and, subsequently, some of its financial ratios. This may have a considerable impact on the future value of the company.

The importance of incorporating financial considerations into strategic decisions, in particular supply chain management decisions, has been reported many times in the literature. Shapiro (2004) discusses the links between supply chain, demand, and corporate financial decisions at the strategic level. He mentions the strong interaction between the financial factors and the strategic planning of firms and organizations. In the context of closed-loop supply chain network design, Ramezani et al. (2014) mention that the majority of studies consider the financial aspects as endogenous variables, and only very few studies consider these aspects as exogenous variables used in constraints and in the objective function. It is striking to see that financial considerations are very often considered in the literature as side constraints, but are never in the core of the decision model. The goal of this paper is to fill this gap by proposing a mathematical model for the joint optimization of the supply chain network design and of the firm's value.

2 FINDING A RELEVANT FINANCIAL OBJECTIVE FUNCTION

2.1 Capital structure optimization

The question of defining the optimal capital structure (Modigliani and Miller, 1963) refers to the debt over equity ratio. This question arises when large investments must be decided, which is exactly the case in strategic supply chain management decisions. The corresponding large investments can be financed by the equity and by the debt. In the first case, the necessary funds are supported by the shareholders or generated by the firm's activities. In the second case, they are borrowed from banks and financial institutions. The most significant incentive of debt financing, called *tax shield benefit* (TSB) is related to the corporate income tax system. Given that the interest expenses associated with the debt are tax-deductible, the TSB is proportional to the corporate tax rate as well as the amount borrowed to the bank. It is thus, easy to calculate.

The main risk of debt financing is the possibility of bankruptcy if a firm is unable to repay debts. There is a vast literature dedicated to the evaluation of bankruptcy cost. We consider the *expected bankruptcy cost*, which combines an estimation of the cost of bankruptcy, denoted BC and the probability π of going bankrupt. The expected bankruptcy cost EBC is estimated as follows (Damodaran, 2012):

$$EBC = \pi \times BC.$$

The valuation of the bankruptcy cost BC follows the model of Leland (1994). Let UV represent the *unlevered value* of the firm, i.e. its value under all-equity financing. When bankruptcy occurs, a firm loses a fraction $0 \leq \beta \leq 1$ of its unlevered value. Then,

$$BC = \beta \times UV.$$

Myers (1984) introduced the *trade-off theory*, in which the TSB is balanced by the dead-weight bankruptcy cost. According to this theory, there is a debt to equity ratio, driving the firm to its maximum value.

This mechanism is illustrated by Figure 1. When the debt level increases (horizontal axis), both the value of TSB and BC increase. It is assumed that the tax shield, represented by the black solid line increases roughly linearly, while BC is nonlinear. Thus, the firm's value (represented by the blue curve) first increases, then reaches an optimal value and then decreases. The highest point of the firm's value curve helps determine the optimal debt value.

2.2 Z-score

The Z-score is an econometric scoring tool, developed in the late 60s (Altman, 1968; Beaver, 1968), used in decisions to grant credit limits. It is one of the most popular bankruptcy predictors for companies and organizations. Its main use is to establish a probability of default at 2 years on the basis of 5 financial ratios. We use the following Z-score formula for private manufacturing companies:

$$z = 0.717X_1 + 0.847X_2 + 3.107X_3 + 0.420X_4 + 0.998X_5, \quad (1)$$

where X_1 is the *Working capital/Total assets* ratio, X_2 is the *Retained Earnings/Total assets* ratio, X_3 is the *Earnings Before Interest and Taxes (EBIT)/Total assets* ratio, X_4 is the *Book value of equity/Book value of total liabilities* ratio and X_5 is the *Sales/Total Assets* ratio.

The primary goal of the Z-score is to predict bankruptcy. Its value can be converted to a probability π of bankruptcy with a logistic function (see, e.g. Hillegeist et al. (2014) and Kallunki and Pyykkö (2013)).

$$\pi = \frac{e^{-z}}{1 + e^{-z}}. \quad (2)$$

2.3 Adjusted Present Value (APV)

Let us first recall the definition of the Net present Value (NPV). It is defined as the value of a project's future cash flows (positive or negative), translated into today's money i.e., the difference between a project's value and its costs over time. Given a set T of time periods, the values of the profit and fixed assets at each period $t \in T$ and the cost of equity r_E, $NPV = \sum_{t \in T} \frac{Profit_t - FixedAsset_t}{(1+r_E)^t}$ is used as an objective function in numerous SCND papers, especially in models describing real-life applications or complex supply chains.

The Adjusted Present Value (APV), proposed by Myers (1974) is mainly used for the valuation of investment projects. Practically, it is calculated as follows:

$$APV = NPV + TSB - EBC. \quad (3)$$

The main principle of the APV is to adjust the unlevered value of the firm by considering the debt effect. The total enterprise value equals the sum of the values of the operating assets plus the present value of debt tax shields. The main contribution of our mathematical model is to adopt APV as the objective function in a classical SCND model, instead of classical cost based objective functions, so as to maximize the overall firm's value.

3 PROBLEM SETTINGS AND MATHEMATICAL FORMULATION

3.1 Problem statement

We consider a supply chain consisting of a set I of customers delivered from a set J of potential production centers belonging to the same company. Customers' locations and demands are known and considered deterministic over a time horizon T decomposed in discrete time periods, typically years. We also define $T^* = T \backslash \{0\}$. The main goal of the SCND problem is to select a subset of production centers among the whole set J and to assign customers' demand to these production centers, at each time period, so as to maximize the adjusted present value of the company.

Satisfying customers' demand requires a certain number of logistic decisions: opening production facilities, setting production levels and carrying the goods from facilities to customers. The mathematical model presented in this section aims at determining the list of

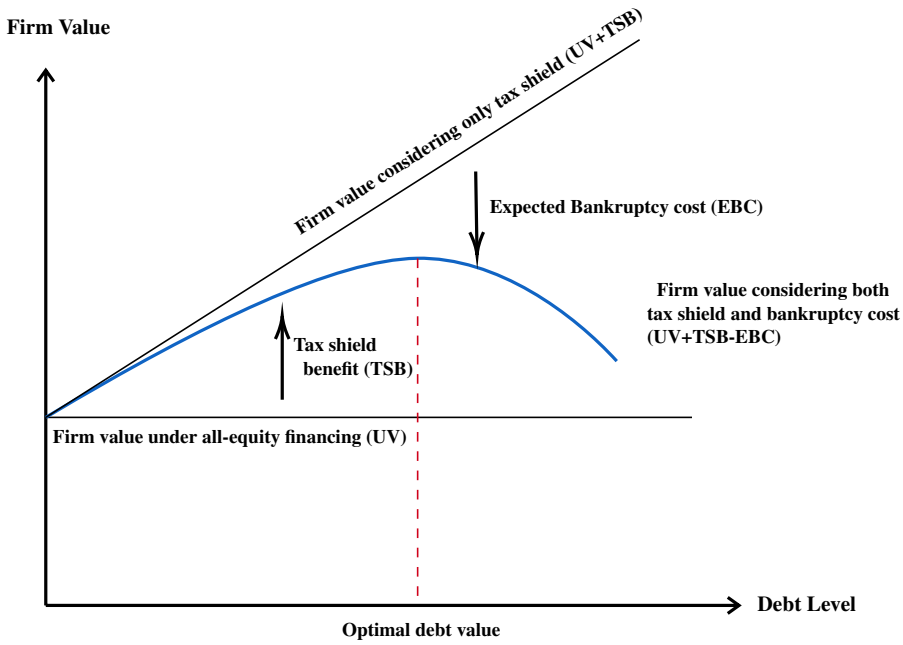

Figure 1 – Trade-off theory for the determination of the optimal debt value

candidate facilities selected, and the product flows from these facilities to customers at each time period, in order to maximize an objective function based on both financial and logistic goals. Since one of the main goals of this paper is to show the interactions between logistic and financial decisions, we adopted a set of simple logistic rules that are not too constraining. We assume that there is no closing option for the facilities. In other words, once a facility is selected, it will stay open until the end of the time horizon. The generalization of this work to a network with both opening and closing options does not raise theoretical difficulties.

The main assumption is that it is not mandatory to serve every particular customer's demand. This can be justified by at least two reasons. First, some customers may be simply too far from production centers, so that delivering them would result in a loss of money. Second, enforcing the delivery to all customers would generate unrealistic solutions in which large fixed cost would be paid to open facilities that deliver only a few customers. We do not impose any single sourcing constraint: customers can be delivered from distinct facilities at distinct periods. However, no partial satisfaction of a particular customer's demand is authorized. Moreover, if a customer's demand is satisfied within a given time period, then it must be satisfied again in all subsequent time periods. Unsatisfied customers' demands are simply lost ; back-orders are not authorized. For each time period, the fraction of the total demand that is satisfied is called *fill rate*.

All supply chain operations have a potentially large cost that must be financed with either debt or equity. Companies generally mix debt financing and equity financing. Thus, for a given decision, the amount to be borrowed to banks and the duration of repayment varies with respect to this mix. We define a set B of available bank offers. Each bank offer is modeled by a tuple containing the maximum amount of money that can be borrowed, an interest rate and a repayment duration.

Incorporating financial decisions into an SCND problem amounts to select a subset of candidate bank offer and optimize the financial flows of the company. The objective function of the optimization problem considered is to maximize the firm's value at the end of the time horizon, where the APV described in section 2.3 is used as a proxy for the firm's value. We consider only two modes for financing supply chain strategic decisions: equity (using the available cash accumulated in previous periods) and debt (selecting bank offers). This study does not consider capital increase, which decision depends on strategic objectives that can hardly be modeled by mathematical models. Moreover, our decision making framework does not consider any decision at the tactical or operational decision levels. The next sections detail the proposed MILP formulation. Section 3.2 describes the variables and constraints related to logistic decisions. Section 3.3 does the same for financial decisions. Section 3.4 describes the calculation of the APV.

3.2 Logistic constraints

For any $j \in J$ and $t \in T$, the binary variables y_{jt} equal 1 if the facility $j \in J$ is selected at period $t \in T$, and 0 otherwise. As mentioned before, once a facility is selected, it cannot be closed later. Besides, the number of facilities selected is bounded above by a number J_{max}. These assumptions are modeled by constraints (4) and (5).

$$y_{j,t-1} \leq y_{jt} \qquad \forall j \in J, t \in T^* \tag{4}$$

$$\sum_{j \in J, t \in T^*} y_{jt} - y_{j,t-1} \leq J_{max} \tag{5}$$

Constraints (6), (7), (8) and (9) are related to the delivery of customers. Due to different trade rules between geographical areas as well as various logistic constraints, it might be practically impossible to deliver some customers from some facilities. Thus, we introduce the binary notation v_{ij} which is set at value 1 if the customer $i \in I$ can be delivered by the facility $j \in J$. Moreover, we denote by q_{ijt} the quantity delivered by facility $j \in J$ to customer $i \in I$ at time period $t \in T$.

With these notations, constraints (6) set q_{ijt} to 0 if customer $i \in I$ cannot be served by facility $j \in J$ or if facility $j \in J$ is not operating at period t. The binary variables θ_{it} take value 1 if customer $i \in I$ is served at period $t \in T$, and 0 otherwise. Constraints (7) calculate the total quantity delivered to each customer. It is either 0 (when $\theta_{it} = 0$) or the value of the customer's demand.

According to the constraints (8), once a customer is served, it will be served at all subsequent periods. The capacity constraints (9) enforce the total quantity shipped by one facility $j \in J$ to be at most equal to its capacity k_j. Note that with these constraints, one can model several possible sizes of facilities, by setting several candidate facilities, with distinct capacities, at the same location.

$$q_{ijt} \leq v_{ij}\ d_{it}\ y_{jt} \qquad \forall i \in I, j \in J, t \in T^* \tag{6}$$

$$\sum_{j \in J} q_{ijt} = d_{it}\ \theta_{it} \qquad \forall i \in I, t \in T^* \tag{7}$$

$$\theta_{it} \geq \theta_{i,t-1} \qquad \forall i \in I, t \in T^* \tag{8}$$

$$\sum_{i \in I} q_{ijt} \leq k_j\ y_{jt} \qquad \forall j \in J, t \in T^* \tag{9}$$

The constraints (10)–(13) calculate the costs related to the manufacturing and transportation of goods. Each candidate facility $j \in J$ has a fixed cost f_j, which is paid once when the facility is selected, as well as the processing cost μ_j for each unit of product processed by this facility. We consider a unit transportation cost w. Without loss of generality, it is the same in the whole network. The distance $dist_{ij}$ between two locations $j \in J$ and $i \in I$ is denoted as $dist_{ij}$.

Constraints (10) calculate the total processing cost $ProcCost_t$ at time period $t \in T$ by summing the processing costs at every production center. Constraints (11) give an estimate of the total transportation cost $TrnCost_t$ at period $t \in T$. Constraints (12) compute the sum of the fixed cost of selected candidate locations. Finally, constraints (13) calculate the total amount of logistic expenses Exp_t at time period $t \in T$.

$$ProcCost_t = \sum_{j \in J} \mu_j \sum_{i \in I} q_{ijt} \quad \forall t \in T^* \tag{10}$$

$$TrnCost_t = w \times \sum_{i \in I} \sum_{j \in J} dist_{ij} \times q_{ijt} \qquad \forall t \in T^* \tag{11}$$

$$FixedCost_t = \sum_{j \in J} f_j \times y_{jt} \qquad \forall t \in T^* \tag{12}$$

$$Exp_t = ProcCost_t + TrnCost_t + FixedCost_t \quad \forall t \in T^* \tag{13}$$

Considering a selling price p_i to customer $i \in I$, the total revenue Rev_t at period $t \in T$ is calculated with constraints (14).

$$Rev_t = \sum_{j \in J} \sum_{i \in I} p_i \times q_{ijt} \qquad \forall t \in T^* \tag{14}$$

3.3 Financial constraints

In this section, we present the financial constraints that relate to debt, equity, or a combination of both.

3.3.1 Debt Financing

Debt refers to the money borrowed to financial institutions on certain conditions subject to return. We consider a set B of bank offers, each of them consisting of an upper bound Z_b on the amount borrowed, a duration N_b (in years) of reimbursement, an interest rate α_b. The variables $Borrow_{bt}$ represent the amount of bank offer b borrowed at period t. If some bank offer $b \in B$ is activated at period t_b, then the reimbursement period is the interval $[t_b + 1, t_b + N_b]$. The amount of bank offer b repaid at period $t \in [t_b + 1, t_b + N_b]$ is denoted $Repay_{bt}$.

The constraints (15) introduce the upper bounds Z_b while the constraints (16) calculate the value of $Repay_{bt}$ for each bank-offer and each period of interest, with the corresponding financial mathematics formula.

$$Borrow_{bt} \leq Z_b, \quad \forall b \in B, t \in T^* \quad (15)$$

$$Repay_{bt} = \frac{Borrow_{bt_b}\ \alpha_b\ (1+\alpha_b)^{N_b}}{(1+\alpha_b)^{N_b} - 1} \quad \forall b \in B, t \in [t_b+1, t_b+N_b] \quad (16)$$

We define D_{bt} as the current debt associated with bank offer $b \in B$ at time period $t \in T \backslash \{0\}$. Given the interest rate α_b, the value of the interest at period t is given by constraints (17). The constraints (18) model the calculation of the current value D_{bt} of the debt related to bank offer b at period t. It is the value at the preceding period, augmented by the interest I_{bt} as well as the possible additional amount borrowed, and decreased by the amount repaid. In constraints (19), we define the total debt $Debt_t$ of the company at period t. Constraints (20) state that this total debt should not exceed some maximal level $MaxDebt$.

$$I_{bt} = \alpha_b\ D_{b,t-1} \quad \forall b \in B, t \in T^* \quad (17)$$

$$D_{bt} = D_{b,t-1} + I_{bt} + Borrow_{bt} - Repay_{bt} \quad \forall b \in B, t \in T^* \quad (18)$$

$$Debt_t = \sum_{b \in B} D_{bt} \quad \forall t \in T \quad (19)$$

$$Debt_t \leq MaxDebt \quad \forall t \in T \quad (20)$$

3.3.2 Equity Financing

Equity refers to the money supported by shareholders and also a portion of the generated revenues plowed back into the company after paying out the expenses as well as the shareholders' dividends. Assuming that there is no possibility of capital increase, equity is defined in the form of internal funds. Internal funds, which are used to be invested for the firms' long-term purposes, are a portion of cash left over for the companies. Thereby, internal funds at period $t \in T$, IF_t, are restricted by the available cash at the end of the preceding period, $Cash_{t-1}$, as stated in constraints (21)

$$IF_t \leq Cash_{t-1} \quad \forall t \in T. \quad (21)$$

In order to introduce constraints related to cash management, we first define intermediate notations in equations (22) to (26). First, the depreciation represents a yearly decrease of tangible assets' value over time. There are different methods to depreciate the firm's assets. Following Laínez et al. (2007), we implement the *straight-line* approach to calculate the depreciation of each facility $j \in J$ as a function of its initial value, IV_j, salvage value, SV_j, and lifetime, LT_j, according to the constraints (22).

$$Dep_j = \frac{IV_j - SV_j}{LT_j} \quad \forall j \in J \quad (22)$$

Constraints (23) define the yearly changes in the value of the fixed asset, ΔFA_t. It results from the opening cost o_j of the facilities and from the depreciation Dep_j.

$$\Delta FA_t = \sum_{j \in J} (o_j(y_{jt} - y_{j,t-1}) - Dep_j \times y_{j,t-1}) \quad \forall t \in T \quad (23)$$

The net changes in debt liabilities due to the bank at period $t \in T$, ΔLib_t, is computed by the constraints (24).

$$\Delta Lib_t = \sum_{b \in B} (Borrow_{bt} - Repay_{bt} + I_{bt}) \quad \forall t \in T \quad (24)$$

In constraints (25), the Earning Before Interest and Taxes (EBIT) at period $t \in T$, denoted $EBIT_t$, is the difference between the firm's revenues and expenses (before interest and tax) at period $t \in T$. A depreciation factor is considered for all open facilities.

$$EBIT_t = Rev_t - Exp_t - \sum_{j \in J} Dep_j \times y_{j,t-1} \quad \forall t \in T \quad (25)$$

In constraints (26), $NOPAT_t$ expresses the net operating profit after taxes of period $t \in T$. By definition, it is obtained by subtracting the interest expenses from the EBIT at period $t \in T$, and then multiplying the result by the term $(1-\tau)$, where τ is the firm tax rate.

$$NOPAT_t = (EBIT_t - \sum_{b \in B} I_{bt}) \times (1-\tau)$$

$$\forall t \in T \quad (26)$$

At the strategic decision level, the level of cash at period $t \in T$, $Cash_t$, is a function of available cash at the end of the preceding period, $Cash_{t-1}$, net operating profit after tax, $NOPAT_t$, net changes in long-term investment, ΔFA_t, and net changes in long-term liabilities, ΔLib_t. Constraints (27) represent the above-mentioned relation.

$$Cash_t = Cash_{t-1} - \Delta FA_t + NOPAT_t + \Delta Lib_t \quad \forall t \in T \quad (27)$$

Constraints (28) explain how facility location decision are funded, either by internal funds (IF_t) or by the debt.

$$\sum_{j \in J} o_j (y_{jt} - y_{j,t-1}) = \sum_{b \in B} (Borrow_{bt}) + IF_t \quad \forall t \in T \quad (28)$$

3.4 Objective function

The objective function to be maximized is the Adjusted Present Value (APV), briefly introduced in equation (3). The detailed formulation of APV is given by equation (29).

$$APV = \sum_{t \in T} \frac{FCF_t}{(1 + r_E)^t} + \sum_{t \in T} \sum_{b \in B} \frac{\tau \times I_{bt}}{(1 + \alpha_b)^t} - \pi \times BC \quad (29)$$

The first term of this objective function is based on the Future cash flows (FCF_t), that measure the firm's ability to generate cash. In other words, FCF_t is defined as the difference between both operating and non-operating cash inflows and outflows. Constraints (30) indicate how to calculate this indicator.

$$FCF_t = (1 - \tau) EBIT_t - \Delta FA_t \quad \forall t \in T, \quad (30)$$

In equation (29), the parameter r_E represents the cost of equity.

The second term of the objective function represents the net present value of the Tax Shield Benefit (TSB). The last term is the Expected bankruptcy Cost (EBC), which mainly depends on the Z-score value. The following set of equations defines the Z-score components listed in section 2.2.

The *total assets* for every period $t \in T$, denoted TA_t, is expressed by constraints (31). They include the cash at period t and the book value at period $t \in T$, which is calculated as the accumulated changes in fixed assets value, ΔFA_t, from period 1 to t.

$$TA_t = Cash_t + \sum_{t'=1}^{t} \Delta FA_{t'} \quad \forall t \in T \quad (31)$$

The *retained earnings* are defined as the net income left over for the company after distributing the dividends to its shareholders. With regards to ignoring the capital expenditures, no dividends are considered. Therefore, RE_t, which represents the value of retained earnings at the period t, is simply obtained using the constraints (32).

$$RE_t = RE_{t-1} + NOPAT_t \quad \forall t \in T \quad (32)$$

The *book value of equity* equals the sum of the retained earnings and the paid-in capital by the shareholders. However, ignoring capital expenditure, BE_t, which is the book value of equity at period $t \in T$ is represented by the constraints (33).

$$BE_t = RE_t \quad \forall t \in T \quad (33)$$

The *book value of liabilities*, BL_t, is defined as the portion of long-term debts due to the bank at period $t \in T$. It is formulated in the constraints (34).

$$BL_t = \sum_{b \in B} \sum_{t'=1}^{t} (Borrow_{bt'} - Repay_{bt'} + I_{bt'}) \quad \forall t \in T \quad (34)$$

Finally, the *sales*, at period $t \in T$ are directly given by the variables Rev_t defined by the equation (14).

Note that the Z-score components used in the mathematical model ($X_2 = RE_t/TA_t$, $X3 = EBIT_t/TA_t$, $X4 = BE_t/BL_t$ and $X5 = Rev_t/TA_t$) are all nonlinear. The linearization of these ratios is fully detailed in Rezaei et al. (2020).

4 NUMERICAL EXPERIMENTS

This section presents the computational experiments conducted to evaluate the performance of the pro-

posed mathematical model. To this aim, we generated a set of instances. The number of customers in these instances is between 60 and 180, and the number of candidate facilities is always 10% of the number of customers. Extensive details about the data generation can be found in Rezaei (2020).

FCF is used as an objective function in many SCND models. Thus, the impact of handling financial indicators in our model is highlighted through a comparison between the results of APV maximization and of the FCF maximization. Concretely, we compare two models: (i) a restricted model whose objective function is $\sum_t FCF_t$ and where the only equity financing constraints considered are those related to FCF_t and (ii) an exhaustive model whose objective function is the APV and with all constraints considered.

For each instance, the network configurations obtained under FCF and APV maximization are shown in Table 1. The first column of the table represents the instance name, built from the number of customers and the coordinates pattern (R=random, C=clustered). The next five columns detail the list of facilities opened at each time period. The eight column represents the fill rate reached in the final period. In order to compare the FCF– and APV–driven solutions, we have *a posteriori* calculated the APV corresponding to solution obtained under FCF maximization. The percentage indicated in the ninth column represents the gap between both APVs.

To get a more detailed picture of the model's decision mechanism, Figures 2 and 3 present the optimal network configurations for instance 150-C, obtained under FCF or APV maximization, respectively.

The map represented in Figures 2 and 3 is divided into 3 markets standing for different economic parameters. The markets are represented by different colors. As presented in table 1, maximizing FCF amount to open facilities 1,4,7 and 11 at period 1, facility 14 at period 2 and facility 8 at period 4. Maximizing APV amounts to select the same facilities at different time periods. The first reason for this difference is the impact of the tax shield benefit, which is higher in APV maximization. After opening facilities 1,4 and 11 at period 1, the company has used almost all its debt capacity. It still can open facility 7 in the first period using equity financing or open facility 7 at a later period using a larger debt capacity. The same mechanism explains the more gradual network expansion under APV maximization.

The second reason is the time value of money, which is ignored by FCF. Opening facility 7 at period 2 rather than at period 1 as well as opening facility 14 at period 3 rather than at period 2 leads to a lower fill rate (we recall that the firm is nonsensitive to the consumer's behavior and that no back-order cost is

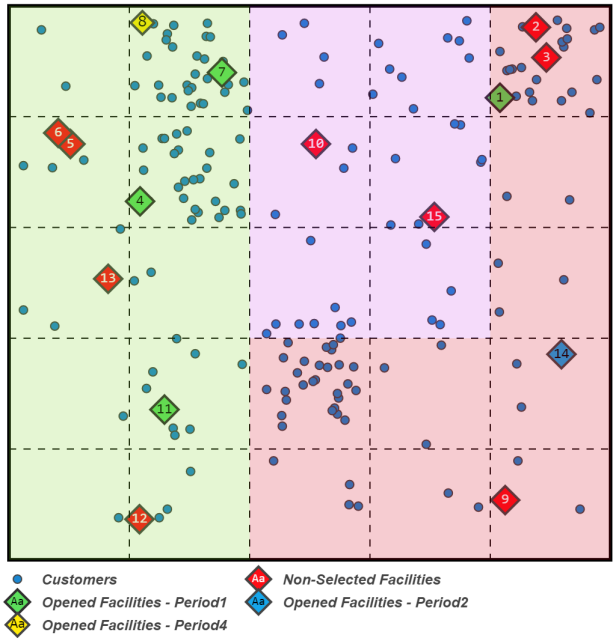

Figure 2 – Instance 150-C: network under FCF maximization

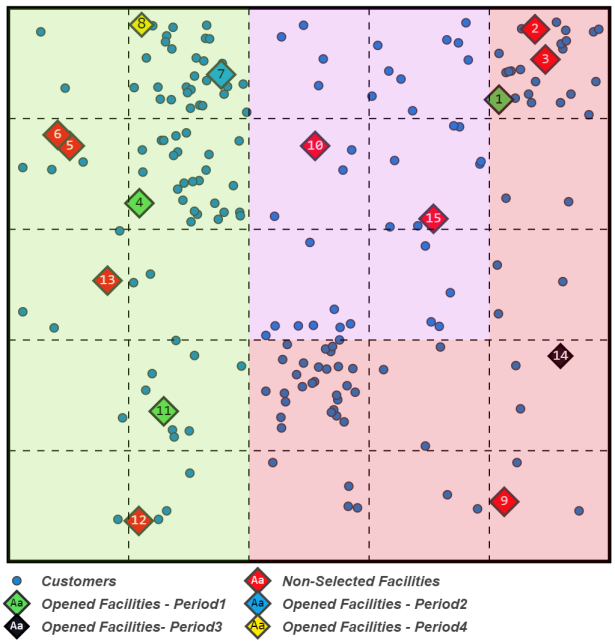

Figure 3 – Instance 150-C: network under APV maximization

Instance	Objective function	Open Facilities					Fill Rate	Firm value gap
		t=1	*t=2*	*t=3*	*t=4*	*t=5*		
60-R	FCF	1,3		6			84%	8.5%
	APV	1	6				50%	
60-C	FCF	2,5	1				86%	6.5%
	APV	2.5					61%	
90-R	FCF	1,2,4					74%	0%
	APV	1,2,4					74%	
90-C	FCF	3,6	2				73%	3.5%
	APV	3,6		2			72%	
120-R	FCF	3,4,9	8	10,12			91%	2.5%
	APV	4,5,9	10	8,12			91%	
120-C	FCF	2,4,5,6,12					98%	2.5%
	APV	2,4,5,12	6				97%	
150-R	FCF	6,7,10,11,14	3				89%	3.5%
	APV	6,7,10,11,14		3			87%	
150-C	FCF	1,4,7,11	14		8		84%	11%
	APV	1,4,11	7	14	8		83%	
180-R	FCF	2,3,5,11,12,16					75%	6%
	APV	2,3,5,11,16		12			74%	
180-C	FCF	7,9,11,14,18	13				85%	4%
	APV	7,9,11,18	13				73%	

Table 1 – Network configuration under FCF and APV

assumed for unsatisfied customers), higher tax shield benefit and lower investment value due to the time value of money.

5 CONCLUSION

In this paper, we proposed an extension of traditional supply chain network models, driven by financial considerations. We propose to use the Adjusted Present Value (APV) as a performance indicator and show that this indicator enables decision makers to find a trade-off between logistic and financial priorities. The mathematical model is tractable by state of the art mixed integer linear programming solvers for realistic sizes of instances, opening perspectives for real-life applications. The numerical experiments show that using APV instead of traditional indicators does not bring considerable changes in the final configuration of the supply chain, but modifies its temporal implementation and can increase the firm value up to around 10%. Besides, focusing on the firm value rather on logistic costs tends to decrease the fill rate, i.e. the satisfaction of customers' demand. Further research could aim at investigating the trade-offs between the interest of various supply chain stakeholders.

ACKNOWLEDGMENT

This work has been supported by ANR under the FILEAS-FOG - ANR-17-CE10-0001 project.

Altman, E. I. (1968). Financial ratios, discriminant analysis and the prediction of corporate bankruptcy, *The Journal of Finance*, 23(4): 589-609.

Beaver, W. H. (1968). Market prices, financial ratios, and the prediction of failure, *Journal of Accounting Research*, 6(2): 179-192.

Damodaran, A. (2012). Investment valuation: Tools and techniques for determining the value of any asset, Vol. 666, John Wiley & Sons.

Hillegeist, S.A., Keating, E.K., Cram, D.P. and Lundstedt, K.G. (2004). Assessing the Probability of Bankruptcy, Review of Accounting Studies,9,5-34.

Kallunki, J.-P. and Pyykkö, E. (2013). Do defaulting CEOs and directors increase the likelihood of financial distress of the firm?, Review of Accounting Studies, 18, 228-260.

Laínez, J.M., Guillén-Gosálbez, G., Badell, M, Espuña, A. and Puigjaner, L., (2007). Enhancing corporate value in the optimal design of chemical supply chains, *Industrial & Engineering Chemistry Research*, 46(23): 7739-7757.

Leland, H. E. (1994). Corporate debt value, bond covenants, and optimal capital structure, *The journal of finance*, 49(4): 1213-1252.

Modigliani, F. and Miller, M. H. (1963). Corporate income taxes and the cost of capital: a cor-

rection, *The American economic review*, 50(3): 433-443.

Myers, S. C. (1974). Interactions of corporate financing and investment decisions-implications for capital budgeting, *The Journal of Finance*, 29(1): 1-25.

Myers, S. C. (1984). The capital structure puzzle, *The journal of finance*, 39(3): 574-592.

Ramezani, M., Kimiagari, A. M. and Karimi, B. (2014). Closed-loop supply chain network design: A financial approach, *Applied Mathematical Modelling*, 38(15-16): 4099-4119.

Rezaei, H., Bostel, N., Hovelaque, V. and Péton, O. (2020). An adjusted present value based supply chain network design model, Technical report, IMT Atlantique.

Shapiro, J. F. (2004). Challenges of strategic supply chain planning and modeling, *Computers & Chemical Engineering*, 28(6-7): 855-861.