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AN OPTIMAL DESIGN OF COMBINED SUPPLY CHAIN NETWORKS CONSIDERING FINANCIAL RATIOS

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Abstract: *The more common approaches used in supply chain management consider only the physical logistic operations and ignore the financial aspects of the chain. This study presents a supply chain network design model focusing on the interactions between logistic and financial considerations. The model tries to integrate both areas of operations and financial aspects to maximize the value created for shareholders. From the logistic point of view, the main contribution of this paper is to provide the possibility of opening or closing facilities in order to deal with market fluctuations during the planning horizon. It specifies the location of each facility and determines the quantities of the products to be produced and stored to satisfy customers' demands. From the financial point of view, unlike previous models, it considers the amount of loan, bank repayment and new capital from shareholders as decision variables, therefore, it provides managers with an accounts payable policy. The model also imposes lower limit and/or upper limit values for financial ratios in order to support the financial health of the corporation. Moreover, instead of traditional approaches such as maximizing profits or minimizing costs, shareholder value analysis (SVA) is used as a new objective function. To show the advantages of the presented approach, the model was solved by Branch-And-Reduce Optimization Navigator (BARON) solver in GAMS software with data provided from the literature and sensitivity analyses on financial parameters were performed to evaluate the results. The results show that with appropriate financial decisions, creating more value for the company and its shareholders is achievable. The developed model with a new financial approach is able to improve the total created shareholder value by as much as 0.7% larger than the SVA obtained without financial aspects and 0.93% larger than the value created by the basic model.*

Key words: *Supply Chain Network Design (SCND), Financial Decisions, Financial Ratios, Shareholder Value Analysis (SVA)*

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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 profit or minimize logistics costs. The overall financial performance of a company can be affected by its strategic decisions and operational actions and also financial decisions in supply chain management can affect the future tactical and operational decisions (Max Shen, 2007). Therefore, they should be simultaneously considered for optimizing the supply chain network. The importance of incorporating financial considerations into supply chain management decisions has been reported many times in the literaturesuch as studies by Hammami et al. (2008), Klibi et al. (2010), Longinidis and Georgiadis (2014), Ramezani et al. (2014), Mohammadi et al. (2017), Yousefi and Pishvaee (2018), Borges et al. (2018), Asadi et al. (2020), Goli et al. (2020), Ghasemiaslet al. (2021), Shahsavari et al. (2021), Ranjbari et al. (2021), Tsao et al. (2021), Rahman et al. (2021), McNultyet al. (2021), Badakhshan and Ball (2022), Musha et al. (2022), Varnosfaderani et al. (2022) and Molana et al. (2022). However, a limited number ofthese studies have an optimization model that merges supply chain planning with financial decisions such as investment, financing and dividend decisions. Based on the previous studies, there are two different approaches in this field of research. In the first approach, financial considerations are considered as endogenous variables and optimized with other variables. In the second approach, financial aspectsare applied in objective functions and constraints as known parameters.

Financial considerations are very often considered in the literature as side constraints rather than the core of the decision model (Rezaei et al., 2020). 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. This study addresses a deterministic multi-echelon, multi-product and multi-period problem that considers operations and financial decisions simultaneously. In order to integrate financial aspects in supply chain network design, a mixed-integer nonlinear programming (MINLP) model was developed that considers operational and financial decisions simultaneously for designing a deterministic multi-echelon, multi-product, and multi-period supply chain network. To show the model applicability, the data of a case study in literature was employed and solved by using Branch-And-Reduce Optimization Navigator (BARON) solver in GAMS software. The major contributions of this study can be summarized as follows:

- This study presents a mathematical model to solve a supply chain network design problem that considers tactical, strategic and financial decisions at the same time.
- Maximizing the creation of economic value for shareholders measured by shareholder value analysis (SVA) as a new objective function instead of traditional approaches such as maximizing profits or minimizing costs. It has not been still used in the general model in supply chain network design problems.
- Providing the possibility of opening or closing facilities in order to deal with market fluctuations at any time period of the planning horizon.
- The proposed model considers the amount of loan, bank repayment and new capital from shareholders as decision variables, therefore, it provides an accounts payable

policy for the company managers instead of considering that all payments should be paid in cash. This is a contribution to the literature because previous studies consider them as parameters.

- At the strategic level, the model specifies the number and location of each facility. At the tactical level, it determines the products quantities to be produced and stored to satisfy customers demand. Regarding to financial decisions, the model specifies the amount of investment and their sources such as cash, bank debt or shareholders' capital as decision variables and it provides managers with a repayment policy.
- Regarding the constraints, in addition to common operational constraints, we also consider lower limit and/or upper limit values for financial ratios (performance, efficiency, liquidity and leverage), in order to support the financial health of the corporation. In order to retain a better financial performance, the proposed model provides a balance among new capital entries, loans and repayment. With consideration of large cost of new capital entries, the model imposes upper bound on it and to avoid an ever-increasing debt, it considers lower bound for bank repayments. Besides, these benefits our model provides for manager an accounts payable guideline.
- In contrast with basic models in previous studies which have too many assumptions, the presented model uses accounting principles with lessassumptions that made it more realistic. For example, we use the net liabilities in the analysis of financial statements that balances bank loans and payments, determines the exact value of deprecation by knowing the lifetime of each asset in each time period, and applies real cash value instead of pre-determined proportion of profit.

The main steps of this study can be outlined as follows:

- Addressing a SCND problem that simultaneously considers operations and financial decisions and considerations.
- Developing anMINLP (mixed-integer nonlinear programming)model to solve the problem.
- Integrating new financial considerations in the developed model to ensure financial health and growth of the company.
- Testing the applicability and efficiency of the proposed model with data as reported in the literature.
- Comparing the results obtained by the proposed model with the basic model through different criteria to show its applicability and advantages.

The remaining sections of this paper are as follows: In section 2, the relevant studies are reviewed. Section 3 describes the problem and presents a mathematical model for designing a supply chain with financial considerations. Section 4 explains a numerical example and discusses the results. Finally, in Section 5 the conclusions and some suggestions for future studies are given.

2. Literature review

As mentioned before, the available published studies on supply chain network design which simultaneously take operations and financial dimensions into account are still rare. Table 1 presented an overview of studies which integrate financial aspect in the supply change management.

Table 1. Overview of financial studies in supply chain

Paper	Period		Finished produc		Parameters		Objective function				Financial futures			
	Single	Multiple	Single	Multiple	Deterministi	Stochastic	Profit/cost	Change in	EVA	SVA	Financial	Financing(Loan,	Tax	Receive-
Longinidis et al.(2014)		✓		✓		✓			✓		✓		✓	
Ramezani et al.(2014)	✓		✓		✓			✓					✓	✓
Mohammadi et al. (2017)	✓			✓	✓	✓		✓	✓		✓		✓	✓
Alavi and Jabbarzadeh (2018)		✓		✓		✓	✓					✓		
Yousefi and Pishvaee (2018)		✓	✓		✓		✓	✓	✓					✓
Polo et al. (2019)		✓		✓		✓			✓				✓	
Zhang and Wang (2019)		✓		✓	✓		✓						✓	
Brahmi et al. (2020)		✓		✓		✓	✓					✓		
Goli et al. (2020)		✓		✓		✓						✓		
Mohammadi et al. (2020)		✓		✓		✓	✓							
Escobar et al. (2020)		✓		✓		✓	✓						✓	
Yousefi et al. (2021)		✓		✓		✓			✓		✓	✓	✓	
Biglar and Hamta (2021)		✓		✓	✓				✓		✓		✓	✓
Tsao et al. (2021)	✓		✓			✓							✓	
Badakhshan and Ball (2022)	✓					✓			✓				✓	
This study		✓		✓	✓			✓		✓	✓	✓	✓	✓

In these studies, Moussawi-Haidar and Jaber (2013) formulated a nonlinear program to find the optimal order amounts and the payment time of the supplier by using cash management integration. In their model, maximizing cash level and loan amount are financial decisions that need to be made to minimize inventory and financial costs. Longinidis et al. (2014) introduced an MINLP SCN design model that considers the sale and leaseback (SLB) technique model to find the optimal configuration of an SCN, under uncertainty in product demand. Their model's financial objectives are maximizing net operating profits after taxes (NOPAT) and unearned profit on SLB (UPSLB). Ramezani et al. (2014) presented a financial approach that considers financial and physical flows to model a supply chain network design for long-term and mid-term decisions. They applied the change in a company equity as the objective function instead of traditional approaches such as minimizing cost or maximizing profit.

Mohammadi et al. (2017) developed a MILP model to consider financial and physical flows in mid-term and long-term decisions. The objective functions of their study are maximizing the economic value added (EVA), shareholders' equity, and corporate value. Brahmi et al. (2020) addressed the planning problem of which considers physical and financial flows at the same time. In their research, supply chain contracts were combined and supply chain tactical planning was also considered within an uncertain condition; budgetary, environmental, and contractual constraints were also incorporated. They also developed and implemented a planning model on a rolling horizon basis to minimize the impact of uncertainties. Goli et al. (2020) addressed a supply chain network design with uncertain parameters. They presented a model to incorporate the financial flow, constraints of debts, and employment under fuzzy uncertainty with three objective functions: maximize the cash flow, maximize the reliability of raw materials, and maximize the total jobs created.

Biswas (2020) carried out a comparative analysis of the supply chain performances of leading healthcare organizations in India. The study presented an integrated multi-criteria decision-making (MCDM) framework wherein the weights of the criteria were based on experts' opinions using PIvot Pairwise RElative Criteria Importance Assessment (PIPRECIA) method. Then three distinct frameworks such as Multi-Attributive Border Approximation area Comparison (MABAC), Combined Compromise Solution (CoCoSo) and Measurement of alternatives and ranking according to COmpromise solution (MARCOS) for ranking purposes. The results showed that large-cap firms do not necessarily perform well. Further, the results of the three MCDM frameworks demonstrated consistency. Goli and Kianfar (2022) developed a bi-objective mathematical model and Fuzzy ε-constraint method for a closed-loop mask supply chain design with the objectives of increasing the total profit and reducing the total environmental impact is presented. In their problem, there are some potential locations for collection, recycling and disposal centers and the model should decide about location of the established centers as well as the amount of produced masks and raw materials. Babaee Tirkolaee and Serhan Aydin (2022) designed a bi-level DSS to configure supply chain and transportation networks and address the sustainable development of the problem by developing two MILP models. They applied a fuzzy weighted goal programming approach to deal with multi-objectiveness. Babaeinesami et al. (2022) addressed a closed-loop supply chain (CLSC) network design considering suppliers, assembly centers, retailers, customers, collection centers, refurbishing centers, disassembly centers and disposal centers to design a distribution network based on customers' needs and simultaneously minimize the total cost and total CO_2 emission. To tackle the complexity of the problem, a self-adaptive, non-dominated sorting genetic algorithm II (NSGA-II) algorithm is designed, which is then evaluated against the ε-constraint method. Sadeghi Darvazeh et al. (2022) proposed a hybrid methodology to expose the process of this problem which helps managers learn how they can determine the optimal number of suppliers. They addressed this gap by developing an integrated approach based on multi-criteria decision-making (MCDM) comprising best-worst method (BWM), simple additive weighting (SAW), and a technique for order preference by similarity to ideal solution (TOPSIS), and simulation to determine the optimal number of suppliers.

Babaee Tirkolaee et al. (2022) developed a novel mixed-integer linear programming (MILP) model for MSW management. The objectives were to simultaneously minimize the total cost and total environmental emission, maximize citizenship satisfaction and minimize the workload deviation. To treat the problem efficiently, a hybrid multi-objective optimization algorithm, namely, MOSA-MOIWOA is designed based on the multi-objective simulated annealing algorithm (MOSA) and multi-objective invasive weed optimization algorithm (MOIWOA).

Mondal et al. (2022) developed an integrated model and three manufacturer-led decentralized models depending on different collection options of used products under selling price and corporate social responsibility efforts. The aim of their study was to explore how the corporate social responsibility effort of a retailer can influence the optimal decisions of the supply chain members. Alinezhad et. al (2022) developed a multi-product, multi-period problem which is formulated by a bi-objective mixed-integer linear programming model with fuzzy demand and return rate . The objectives of their model are to maximize the supply chain profit and customer satisfaction at the same time. Moreover, the carbon footprint is included in the first objective function in terms of cost (tax) to affect the total profit and treat the environmental aspect. They applied the fuzzy linear programming and Lp-metric method to deal with the uncertainty and bi-objectiveness of the model, respectively. Babaee Tirkolaee et al. (2022) developed a novel mixed-integer linear programming (MILP) model for MSW management. The objectives were to simultaneously minimize the total cost and total environmental emission, maximize citizenship satisfaction and minimize the workload deviation. To treat the problem efficiently, a hybrid multi-objective optimization algorithm, namely, MOSA-MOIWOA is designed based on the multi-objective simulated annealing algorithm (MOSA) and multi-objective invasive weed optimization algorithm (MOIWOA).

Based on the above-mentioned works, this study suggests a mathematical model that simultaneously considers physical and financial aspects in a supply chain planning problem. A deterministic Mixed Integer Nonlinear Programming (MINLP) model is developed to specify the number and location of facilities and the links between them. The model also determines the quantities to be produced, stored and transported in order to meet customers' demands as well as maximize shareholder value analysis (SVA). As financial decisions, we consider the amount to invest, the source of the money needed (cash, bank loan, or new capital from shareholders), and repayments to the bank.

3. Problem definition and assumptions

In this study, a multi-echelon, multi-period, and multi-product supply chain was discussed.The supply chain consists of plants, warehouses, distribution centers and customer zones. The problem incorporates operational and financial decisions simultaneously, therefore, the mathematical formulation needs proper variables and parameters.The facilities' parameters also are independent of each other.The objective function and financial constraints are calculated based on the study by Blyth et al. (1986), Brealey et al. (2011) and Borges at al. (2018). The goals of the proposed model are to determine:

- Strategic decisions about the facilities to be established (opening or closing) in given locations and the supply routes among them for each time period.
- Tactical operation decisions regarding the quantity produced for each product at each factory, the materials flow between facilities and the levels of inventory that consist of maximum inventory at plants, products safety stock and max and min inventory of products at warehouses and distribution centers.

- Financial decisions for determining the amount of bank loans, new capital entries and total investments to establish the network and the quantity of repayments to the bank for each time period.

These three kinds of decisions were made for maximizing the value of company at the end of planning horizon that was measured by Shareholder Value Analysis(SVA) as an indicator of the corporation profitability (Biglar et al., 2021). As presented in the previous sections, supply chain strategic decisions and its operation impact corporate finances and consequently financial value created for shareholders. SVA is a method that values the whole equity in a company. This method assumes that the value of a business is the net present value of its future cash flows, discounted at the appropriate cost of capital. Once the value of a business is calculated, the next step is to calculate the shareholder value by the equation:

$$shareholder\ value = value\ of\ business - debt$$

This method was first presented by Alfred Rappaport in the 1980s.That shows how well the company utilizes its properties in order to create value. This method is one of the most accepted lines of thought on how the corporate performance relates to the shareholder value (Brealey et al., 2011).

Moreover, the assumptions of the proposed model can be summarized as follows:

- In each duration, the demand of each customer zone is clear.
- To satisfy customers' demands, the company can decide what kind of facilities to be involved at a particular time.
- Products can be kept at the company as inventory or distributed among warehouses.
- There is not any back-order.
- Transportation of products among different facilities has capacity limitation.
- Cost and revenue are derived from the operation of firm.
- Fixed and variable expenses are related to transportation and production.
- The establishment of facilities has fixed costs.
- Financial considerations are defined regarding capital cost, financial ratios, tax and depreciation rates and long-term borrowing.

3.1 Mathematical formulation

The decision variables, parameters, and indices applied in the mathematical model of this study have been presented in the appendix.

3.2 Objective function

As presented in the previous sections, strategic and operational decisions in supply chain management impact company financial performance and, consequently, the financial value created for shareholders. Shareholder value is the value delivered to the equity owners of a corporation; it is created when earnings exceed the total costs of invested capital (Brealey et al., 2011). Therefore, in this study shareholder value analysis (SVA) was applied as an objective function in order to maximize shareholder value created with the supply chain network configuration.

SVA calculates the shareholder value (or equity value) by deducting the long-term liabilities value at the end of the project lifetime ($LTDT$) from the firm value for the time period under analysis. Equation (1) shows the objective function.

$$max\ SVA = DFCF - LTD_T \tag{1}$$

Now, we explain $DFCF$, $LTDT$ and other components involved to calculate them.

As given by equation (2), the discounted free cash flow ($DFCF$) is obtained by adding the summation of the discounted free cash flows ($FCFF_t$) to the terminal value of a firm (VT) over the planning period.

$$DFCF = \sum_{t\in\mathcal{T}} \frac{FCFF_t}{(1+r_t)^t} + \frac{V_T}{(1+r_T)^T} \tag{2}$$

Note that T shows the number of time periods of the planning horizon. (r_T) is a parameter to show the discount rate and cost of capital and represents the time value of money and investment risk. Also, V_T shows the final value of the firm, that is, the value of total future cash flows, beyond the planning horizon. In this study, V_T is calculated by the growing perpetuity model, which presumes that free cash flows grow at a fixed rate (g) constantly. Equation (3) shows how the terminal value of the firm is calculated.

$$V_T = \frac{FCFF_{T+1}}{r_T - g} \qquad \forall t \in T \tag{3}$$

Because we estimate $FCFF_{T+1}$ based on an adjustment to FCFF from the last period of the planning horizon, making it grow at fixed rate g (see Equation (4)), therefore modification in the FCFF is needed since we have assumed stability beyond the planning horizon. This means that non-operating income is considered zero and new investments will be offset by depreciation.

$$FCFF_{T+1} = [(REV_T - CS_T - DPV_T)(1 - TR_T) - \Delta WC_T](1 - g) \tag{4}$$

3.2.1. Free cash flow to the firm (FCFF)

FCFF represents the quantity of cash flow from operations after accounting for depreciation expenses, taxes, working capital, and investments. It is calculated by equation (5) which deducts the net fixed asset investment ($FAIt - DPVt$) and the changes in working capital (ΔWCt) from the operating income after taxes. In this quation, ($REVt$) is the revenue, the non-operating income (NOI), the icost of sales (CSt), and depreciation ($DPVt$).

Note that operating earnings are a taxable revenue; it means that in order to get net income, taxes must be subtracted from incomes. The tax rate (TRt) is according to current tax laws.

As shown in equation (5), depreciation is considered a cost because it decreases taxable income, and it is not related to a real payment (cash outflow). This means that in order to calculate the ($FCFF_t$), depreciation has to be added again.

$$FCFF_t = (REV_t + NOI_t - CS_t - DPV_t)(1 - TR_t) - (FAI_t - DPV_t) - \Delta WC_t. \quad \forall t \in T \tag{5}$$

Next, the free cash flow components will be explained in more detail.

3.2.2. Revenues

The revenues (REV_{t}) coming from selling products/providing services are calculated as shown in equation (6):

$$REV_{\mathrm{t}} = \sum_{\mathrm{i \in I. l \in L}} \mathrm{PR_{ilt} O_{ilt}} \quad \forall \mathrm{t} \in \mathrm{T} \tag{6}$$

3.2.3. Non-operating income (NOI_t)

NOI_{t} is the portion of a firm's income that is derived from activities not related to its core business operations including gains/losses from property or property sales. Therefore, in a period that physical assets are not sold, the non-operating income will be zero. In this model, we have assumed that if there is a decision to close a facility, it will be sold. As shown in equation (7), the NOI_{t} consists of three income components derived from the sale of plants, warehouses, or distribution centers. The profit or loss from selling a plant is the difference between the cash inflow resulting from alienation and calculated by the market price of the plant for the period ($\mathrm{A_{jt}^{P}}$) minus the cost of closing it ($\mathrm{C_{jt}^{P-}}$) and the plant net value.

$$NOI_{\mathrm{t}} = \sum_{\mathrm{j \in J}} \left(\mathrm{A_{jt}^{P}} - \mathrm{C_{jt}^{P-}}\right) \mathrm{y_{jt}^{P-}} - \sum_{\mathrm{S=1}}^{\mathrm{t}} \mathrm{C_{js}^{P+}} (1 - \mathrm{ACDPR_{st}}) \mathrm{w_{jst}^{P-}}$$

$$+ \sum_{m \in M} (\mathrm{A_{mt}^{w}} - \mathrm{C_{mt}^{w-}}) \mathrm{y_{mt}^{w-}} - \sum_{\mathrm{S=1}}^{\mathrm{t}} \mathrm{C_{ms}^{w+}} (1 - \mathrm{ACDPR_{st}}) \mathrm{w_{mst}^{w-}}$$

$$+ \sum_{k \in K} \left(\mathrm{A_{kt}^{D}} - \mathrm{C_{kt}^{D-}}\right) \mathrm{y_{kt}^{D-}} - \sum_{\mathrm{S=1}}^{\mathrm{t}} \mathrm{C_{ks}^{D+}} (1 - \mathrm{ACDPR_{st}}) \mathrm{w_{kst}^{D-}}. \qquad \forall \mathrm{t} \in \mathrm{T} \tag{7}$$

3.2.4. Cost of sales

As expressed in equation (8), cost of sales (CSt) represents all the expenditures that are needed for producing and delivering products to customers. It consists of four parts: costs of production (PCt), costs of transportation (TCt), costs of inventory holding (ICt), and changes in inventory value ($IV_t - IV_{t-1}$).

$$CS_t = PC_t + TC_t + IC_t - (IV_t - IV_{t-1}) \qquad \forall \mathrm{t} \in \mathrm{T} \tag{8}$$

Production costs have a fixed and variable part, as follows:

$$\mathrm{PC_t} = \sum_{i \in I} \sum_{j \in J} \left(C_{ijt}^{VPP} p_{ijt} + C_{ijt}^{FPP} u_{ijt} \right) \quad \forall \mathrm{t} \in \mathrm{T} \tag{9}$$

In equation (9), C_{ijt}^{VPP} and C_{ijt}^{FPP} represent the variable and fixed cost of production, respectively, at plant j, in time period t. Also, p_{ijt} is the quantity of product i produced in plant j at time period t and u_{ijt} is a binary value which has the value 1 if product i is produced in plant j at the time period t and zero otherwise.

Equation (10) shows the transportation costs which include three parts with fixed and variable costs; these costs are incurred during transporting products from plants to warehouses, distribution centers, and customer zones.

$$TC_t = \sum_{i \in I} \sum_{j \in J} \sum_{m \in M} \left(C_{ijmt}^{VTPW} x_{ijmt}^{PW} + C_{ijmt}^{FTPW} z_{jmt}^{PW} \right)$$

$$+\sum_{i\in I}\sum_{m\in M}\sum_{k\in K}(C_{imkt}^{VTWD}x_{imkt}^{WD}+C_{imkt}^{FTWD}z_{mkt}^{WD})$$

$$+\sum_{i\in I}\sum_{k\in K}\sum_{l\ k\ L}(C_{iklt}^{VTDC}x_{iklt}^{DC}+C_{iklt}^{VTDC}z_{ikt}^{DC})\ \ \forall t\in T \quad (10)$$

Equation (11) shows the total inventory holding costs and it has three parts related to the average quantity held at each facility (plants, warehouses, and distribution centers) during the time period.

$$IC_t=\sum_{i\in I}\sum_{j\in J}\left(C_{ijt}^{IP}\frac{q_{ijt}^{P}+q_{ijt-1}^{P}}{2}\right)+\sum_{i\in I}\sum_{m\in M}\left(C_{imt}^{IW}\frac{q_{imt}^{W}+q_{imt-1}^{W}}{2}\right)+\sum_{i\in I}\sum_{k\in K}\left(C_{ikt}^{ID}\frac{q_{ikt}^{D}+q_{ikt-1}^{D}}{2}\right)\ \forall t\in T \quad (11)$$

Based on accounting principles, the value of inventory is calculated by historical cost; in this case, equation (12) shows the production price for each product at each time period.

$$IV_t=\sum_{i\in I}\sum_{j\in J}\sum_{m\in M}\sum_{k\in K}C_{ijt}^{VPP}\left(q_{ijt}^{P}+q_{imt}^{W}+q_{ikt}^{D}\right)\ \forall t\in T \quad (12)$$

3.2.5. Depreciation

The value of fixed assets such as plants, warehouses, and distribution centers should be modified for devaluation. Based on this accounting rule, the total depreciation value at the time period t (DPV_t) is calculated by the summation of the depreciated value of plants, warehouses, and distribution centers which are operating during the time period t. In this model, we assume that fixed assets existing before the planning horizon have been completely depreciated.

$$DPV_t=\sum_{j\in J}\sum_{s=1}^{t}DPR_{st}C_{js}^{P+}W_{jst}^{P+}+\sum_{m\in M}\sum_{s=1}^{t}DPR_{st}C_{ms}^{W+}W_{mst}^{W+}$$

$$+\sum_{k\in K}\sum_{s=1}^{t}DPR_{st}C_{ks}^{D+}W_{kst}^{W+}\quad \forall t\in T \quad (13)$$

In equation (13), W_{jst}^{P+}, W_{mst}^{W+}, and $W_{kst}^{W+}$are binary variables set to 1 if a facility opened at the time period s is still open at the time period t.

3.2.6. Fixed assets investment

Fixed assets are long-term tangible properties which a firm owns and utilizes in its operations to generate income. In our model, ($FAIt$) represents fixed assets investment at the time period t which is the needed finance to establish facilities (plants, warehouses, and distribution centers) in the time period t:

$$FAI_t=\sum_{j\in J}C_{jt}^{P+}y_{jt}^{P+}+\sum_{m\in M}C_{mt}^{W+}y_{mt}^{W+}+\sum_{k\in K}C_{kt}^{D+}y_{kt}^{D+}\qquad \forall t\in T \quad (14)$$

3.2.7. Changes in working capital

The changes in working capital (ΔWCt) are obtained by the difference between the working capital in two successive periods. The working capital is calculated by adding receivable accounts to the value of inventory and deducting payable accounts. It is assumed that the accounts receivable and the accounts payable are a portion of the revenues and of the operational costs, respectively, at the end of time period t. Therefore, ΔWC_t can be obtained as follows:

$$\Delta WC_t = (\alpha_t REV_t - \alpha_{t-1} REV_{t-1}) + (IV_t - IV_{t-1}) - [\mu_t(PC_t + TC_t + IC_t) - \mu_{t-1}(PC_{t-1} + TC_{t-1} + IC_{t-1})] \ \forall t \in T \quad (15)$$

Note that α_t and μ_t represent the amount of revenues and payments (in percentage), respectively, which are outstanding in the current time period and defined by the company policy on payables and receivables.

3.2.8. Long-term liabilities calculation

Long term liabilities are represented by long-term debt (LTD_t), that is incurred to finance fixed assets investments, and calculated by equation (16). This is a function of the previous period debt value and current period loans (B_t) and bank repayments (RP_t).

$$LTD_t = LTD_{t-1} + B_t - RP_t \ \forall t \in T \quad (16)$$

3.3. The Model constraints

The model constraints can be categorized into two groups that should be satisfied as financial constraints and operational constraints.

3.3.1. Financial constraints

Financial ratios are one of the beneficial parts of financial statements which prepare standard tools to evaluate the overall financial condition of a company's performance, efficiency, liquidity, and leverage. The financial constrains enforce financial ratios in order to support the financial health of the corporation. This study used the ratio categories defined by Blyth et al. (1986) and Breally et al. (2011) and sets upper/lower limits value for them.

3.3.2. Performance ratios

Performance ratios measure the financial performance of the company. In this study we considered two common measures, that is, return on equity (ROE) and return on assets (ROA). Equations (20) and (21) present the least values of ROE_t and ROA_t that have to be satisfied in each time duration.

(i)Return on equity (ROE)

ROE illustrates the marginal investment income of shareholders and is calculated by dividing the net income by shareholders' equity. The net income (NI_t) is what the business has left over after all expenses. Also, ($EBIT_t$) is named earnings before interests and taxes. They are calculated by equations (17) and (18):

$$EBIT_t = REV_t + NOI_t - CS_t - DPV_t \ \forall t \in T \quad (17)$$

$$NI_t = (EBIT_t - IR_t * LTD_t)(1 - TR_t) \ \forall t \in T \quad (18)$$

$$E_t = E_{t-1} + (EBIT_t - IR_t * LTD_t)(1 - TR_t) + NCP_t \ \forall t \in T \quad (19)$$

According to the previous descriptions, the ROE equation can be written as:

$$\frac{(EBIT_t - IR_t * LTD_t)(1 - TR_t)}{E_t} \geq ROE_t \ \forall t \in T \quad (20)$$

(ii) Return on assets (ROA)

ROA is a measure of financial performance and represents the percentage of how profitable a company's assets are for generating revenue. It is calculated by equation (21). Note that in this equation, $(NOPAT)$,(NFA_t) and (CA_t) are the net operating profit after taxes, net fixed assets, and the current assets, respectively.

$$\frac{EBIT_t(1-TR_t)}{+CA_t} \geq ROA_t \qquad \forall t \in T \tag{21}$$

Equation (22) shows how the current net fixed assets (NFA_t) are calculated from those of the previous period, which are increased/decreased in an amount equal to the value of the investment (FAI_t) /divestment (FAD_t) in fixed assets of depreciation in time period t, as follows:

$$NFA_t = NFA_{t-1} + FAI_t - FAD_t - DPV_t \quad \forall t \in T \tag{22}$$

Investment expresses the ownership of fixed assets, while divestment represents sales fixed assets. In this study, we have assumed that before the planning horizon, existing assets were completely depreciated, also (FAD_t) shows the net value (accounting value of the asset after depreciation) of the assets which bought during the planning horizon and until-time period t:

$$FAD_t = \sum_{s=1}^{t} \left[\sum_{j \in J} C_{js}^{P+}(1 - ACDPR_{st})W_{jst}^{P-} + \sum_{m \in M} C_{ms}^{W+}(1 - ACDPR_{st})W_{mst}^{W-} + \sum_{k \in K} C_{ks}^{D+}(1 - ACDPR_{st})W_{kst}^{D-} \right] \qquad \forall t \in T \tag{23}$$

DPV_t and FAI_t reffer to equations (13) and (14) . Current assets are any assets that can be expected to be sold, consumed, or exhausted by the operations of a business. In this study, current assets (CA_t) consist of: cash and banks (C_t); accounts receivable, here represented as a percent of the revenues $(\alpha_t REV_t)$, and inventory value (IV_t):

$$CA_t = C_t + \alpha_t REV_t + IV_t \qquad \forall t \in T \tag{24}$$

Equation (25) represents the cash function during the time duration (C_t). The cash at time period t is the available cash in the previous period, cash inflows, and cash outflows. Cash inflows come from different sources:

- Customer and receivables $(\alpha_{t-1}REV_{t-1})$ and product sales($(1-\alpha_t)REV_t$),
- Fixed assets sales,
- New capital entries (NCP_t),
- Loans of the period to finance investments (B_t).

Also, cash outflows come from different sources:

- Repayments of debt to the bank (RP_t),
- Costs of interest; they are calculated by multiplying an interest rate by the debt of the period $(IR_t LTD_t)$,
- Accounts payable($\mu_{t-1}(PC_{t-1} + TC_{t-1} + IC_{t-1})$ and payments to suppliers

$((1-\mu_t)(PC_t + TC_t + IC_t))$,

- Payment of income taxes of the previous period,

- The amount invested in new assets.

$$\mathrm{C_t} = \mathrm{C_{t-1}} + \alpha_{t-1}\mathrm{REV_{t-1}} + (1-\alpha_t)\mathrm{REV_t} + \left[\sum_{j\in J}(A_{jt}^{P} - C_{jt}^{P-})y_{jt}^{P-} + \sum_{m\in M}(A_{mt}^{W} - C_{mt}^{W-})y_{mt}^{W-} + \sum_{k\in K}(A_{kt}^{D} - C_{kt}^{D-})y_{jt}^{D-}\right]$$

$$+NCP_t + B_t - RP_t - IR_tLTD_t - \mu_{t-1}(PC_{t-1} + TC_{t-1} + IC_{t-1}) - (1-\mu_t)(PC_t + TC_t + IC_t) - TR_{t-1}(EBIT_{t-1} - IR_{t-1}LTD_{t-1}) - FAI_t \quad \forall t \in \mathcal{T} \quad (25)$$

Note that ($\mathrm{REV_t}$) is defined in equation (6) and income taxes are due only if there is a taxable income.

3.3.3. Efficiency ratios

Efficiency ratios measure how well the company utilizes its different assets. These ratios allow the company to evaluate its efficiency. In this study, we considered profit margin (PMR) and asset turnover (ATR) as efficiency ratios.

(i) Profit margin (PMR)

Profit margin is defined as the ratio of net income to sales and must attain a minimum value at each time duration (PMR_t); its ratios are given by equation (26):

$$\frac{(EBIT_t - \mathrm{IR_t LTD_t})(1-TR_t)}{REV_t} \geq PMR_t \quad \forall \mathrm{t} \in \mathrm{T} \quad (26)$$

(ii) Asset turnover (ATR)

ATR the incomes generated per monetary unit of total assets, measuring how hard the firm's assets are working. It is given by the ratio of sales revenue to total assets in time period t. Equation (27) shows asset turnover ratios.

$$\frac{REV_t}{NFA_t + CA_t} \geq ATR_t \quad \forall \mathrm{t} \in \mathrm{T} \quad (27)$$

3.3.4. Liquidity ratios

Liquidity ratios determine how quickly assets can be converted into cash. The liquidity ratios analysis helps the company to evaluate its ability to keep more liquid assets.

(i) Current ratio (CUR)

Current ratio is the ratio of current assets to its current liabilities and must attain a minimum value (CUR_t). Equation (28) shows current ratio constraint:

$$\frac{CA_t}{STD_t} \geq CUR_t \quad \forall \mathrm{t} \in \mathrm{T} \quad (28)$$

As in our model, short-term loans are negligible, thus short-term debt (STD_t) is due to accounts payable and taxes, as follows:

$$STD_t = \mu_t(\mathrm{PC_t} + \mathrm{TC_t} + \mathrm{IC_t}) + (\mathrm{EBIT_t} - \mathrm{IR_t LTD_t})TR_t \quad \forall \mathrm{t} \in \mathrm{T} \quad (29)$$

(ii) Quick ratio (QR)

QR is the ratio of current assets (except inventory) to its current liabilities which must satisfy a threshold value (QR_t) as follows:

$$\frac{C_t+\alpha_t REV_t}{STD_t} \geq QR_t \quad \forall t \in T \tag{30}$$

(iii) Cash ratio (CR)

CR is the ratio of its current liabilities which must satisfy a threshold value (CR_t) as follows:

$$\frac{C_t}{STD_t} \geq CR_t \quad \forall t \in T \tag{31}$$

3.3.5. Leverage ratios

Leverage ratios assess the firm's ability to meet the financial obligations.

(i) Long term debt to equity ratio (LTDR)

LTDR provides an index of how much debt is used to finance its assets in a company. This ratio must be below a given limit:

$$\frac{LTD_t}{E_t} \geq LTDR_t \quad \forall t \in T \tag{32}$$

(ii) Total debt ratio (TDR)

RDR provides an indication on the total amount of debt relative to assets; it is obtained by dividing total debt by total assets, and must be lower a given limit:

$$\frac{STD_t+LTD_t}{NFA_t+CA_t} \geq LTD_t \quad \forall t \in T \tag{33}$$

(iii) Cash coverage ratio (CCR)

CCR measures the firm's capacity to meet interest payments in cash, thus it must satisfy a given lower limit:

$$\frac{\mathrm{EBIT}_t+DPR_t}{\mathrm{IR}_t LTD_t} \geq CCR_t \quad \forall t \in T \tag{34}$$

3.3.6 Other financial constraints

Equation (35) shows that new capital entries are limited to the quantity that company partners desire to invest in the company

$$\mathrm{NCP}_t \leq CP_t \quad \forall t \in T \tag{35}$$

Commonly, banks constrain the repayment (RP_t) to be at least the interest costs to barricade a growing debt:

$$\mathrm{RP}_t \geq \mathrm{IR}_t LTD_t \quad \forall t \in T \tag{36}$$

Furthermore, because repayments (RPt) are part of the debt, in each period they must satisfy the constraint (37):

$$\mathrm{RP}_t \geq LTD_t \quad \forall t \in T \tag{37}$$

For each time period, the company may limit the amount borrowed to the percentage of the value of investments, as follows:

$$\mathrm{B}_t \leq \gamma_t FAI_t \quad \forall t \in T \tag{38}$$

3.6.2. Operational constraints

3.6.2.1. At the plant level

Equations (39) and (40) show that production constraints enforce the production quantities in each time period, each plant, and for each product to be in a specified range.

$$p_{ijt} \leq P_{ij}^{max} \sum_{s=0}^{t} w_{jst}^{P+} \qquad \forall i \in I \ \ j \in J \ \text{ and } t \in T \qquad (39)$$

$$p_{ijt} \leq P_{ij}^{min} \sum_{s=0}^{t} w_{jst}^{P+} \qquad \forall i \in I \ \ j \in J \ \text{ and } t \in T \qquad (40)$$

Production quantities are also collectively limited by the available quantity of each time period, each resource, and each plant (constraint (41). Note that the availability of the resources is fixed over time.

$$\sum_{i \in I}^{t} \rho_{ije} p_{ijt} \leq R_{je} \qquad \forall j \in J \text{ and } \ e \in E \ \text{ and } t \in T \qquad (41)$$

Because production has a fixed cost, in equation (42), a binary variable ($uijt$) is used to show the existence of production that assumes the value 1 whenever some non-zero quantity is produced.

$$p_{ijt} \leq M u_{ijt} \qquad \forall i \in I \text{ and } \ j \in J \ \text{ and } t \in T \qquad (42)$$

Plants might send all or part of the products to the warehouses that have been established. This is stated by equations (43) and (44):

$$\sum_{i \in I} \sum_{m \in M} x_{ijmt}^{PW} \leq M \sum_{s=0}^{t} w_{jst}^{p+} \ \forall j \in J \ \text{ and } t \in T. \qquad (43)$$

$$\sum_{i \in I} \sum_{j \in J} x_{ijmt}^{PW} \leq M \sum_{s=0}^{t} w_{mst}^{W+} \ \forall m \in M \ \text{ and } t \in T. \qquad (44)$$

The total production quantity sent by each plant to each warehouse must satisfy the transport capacity, which is shown by equation (45) (Note that M is enough large number).

$$\sum_{i \in I} x_{ijmt}^{PW} \leq Q_{jm}^{PW} Z_{jmt}^{PW} \forall j \in J \text{ and } \ m \in M \ \ \text{ and } t \in T \qquad (45)$$

Equation (46) is for inventory balance at each plant and each product in each time period. The available inventory is calculated by the available inventory in the previous period, plus the produced quantity in the current period minus the quantity sent to warehouses.

$$q_{ijt}^{P} = q_{ijt-1}^{P} + p_{ijt} - \sum_{m \in M} x_{ijmt}^{PW} \qquad \forall i \in I \text{ and } \ j \in J \ \text{ and } t \in T \qquad (46)$$

Equation (47) shows that at each plant and in each time period, inventory for each product is limited.

$$q_{ijt}^{P} \leq I_{ijt}^{max} \qquad \forall i \in I \ \ j \in J \ \text{ and } t \in T \qquad (47)$$

Finally, the proper auxiliary variables associated with the closing/remaining open status of the facilities should be set to confirm the accuracy of the opening and closing decisions in the model. During the whole planning period, if a plant was not initially open, it can only be opened at most once (equation (48)).

$$\sum_{t \in \mathcal{T}} y_{jt}^{P+} \leq 1 \qquad \forall j \in J \qquad (48)$$

Throughout the planning period, a plant can be closed at most once if it was opened before (equations (49) and (50)).

$$\sum_{t\in\mathcal{T}} y_{jt}^{P-} \leq 1 \qquad \forall j \in J \qquad (49)$$

$$y_{jt}^{P-} \leq \sum_{s=0}^{t-1} y_{js}^{P+} \qquad \forall j \in J \text{ and } t \in T \qquad (50)$$

It is impossible for a plant to be opened and closed in the same time period (equation (51)).

$$y_{jt}^{P+} + y_{jt}^{P-} \leq 1 \qquad \forall j \in J \text{ and } t \in T \qquad (51)$$

Equation (52) illustrates that if a plant was opened in the time period s and then closed in the time period t, therefore all decision variables: opening (y_{js}^{P+}), closing (y_{jt}^{P-}), and closing status (w_{jst}^{P-}) should be set to 1.

$$y_{js}^{P+} + y_{jt}^{P-} \leq w_{jst}^{P-} + 1 \qquad \forall j \in J \text{ and } s = 0. \ \dots T-1 \text{ and } t = s+1. \dots \ T \qquad (52)$$

If only a closing decision was made, the closing status variable would be set to 1:

$$w_{jst}^{P-} \leq y_{jt}^{P-} \qquad \forall j \in J \text{ and } S = 0. \ \dots \mathcal{T}-1 \text{ and } t = s+1. \dots \ T \qquad (53)$$

Also, the opening status variable (w_{jst}^{P+}) would be set to 1 if an opening decision was made:

$$w_{jst}^{P+} \leq y_{js}^{P+} \qquad \forall j \in J \text{ and } s \in \mathcal{T} \text{ and } t = s. \dots \ T \qquad (54)$$

If a plant was opened in the time period s and is yet open in the time period t, in any of the periods in the internal s+1 and t, a closing decision would be impossible:

$$w_{jst}^{P+} - y_{js}^{P+} + \sum_{v=s+1}^{t} y_{jv}^{P-} \leq 0 \qquad \forall j \in J \text{ and } s = 0. \dots T-1 \text{ and } t = s+1. \dots T \qquad (55)$$

3.6.2.2 At the warehouse level

Equations (56) and (57) show that the stored quantities in each warehouse for each product and time period to be within a pre-specified range.

$$\sum_{i\in I} q_{imt}^{W} \leq W_{m}^{max} \sum_{s=0}^{t} W_{mst}^{W+} \qquad \forall m \in M \text{ and } t \in T \qquad (56)$$

$$\sum_{i} q_{imt}^{W} \geq W_{m}^{min} \sum_{s=0}^{t} W_{mst}^{W+} \qquad \forall m \in M \text{ and } t \in T \qquad (57)$$

Active warehouses might send all or part of their products to distribution centers in operation as stated by equations (58) and (59).

$$\sum_{i\in I} \sum_{k\in K} x_{imkt}^{WD} \leq M \sum_{s=0}^{t} W_{mst}^{D+}. \qquad \forall\, m \in M \text{ and } t \in T. \qquad (58)$$

$$\sum_{i\in I} \sum_{m\in M} x_{imkt}^{WD} \leq M \sum_{s=0}^{t} W_{kst}^{D+} \qquad \forall\, k \in K \text{ and } t \in T. \qquad (59)$$

Equation (60) shows that the total quantity sent by warehouses to distribution centers in each time period, if any, must satisfy the transport capacity.

$$\sum_{i\in I} x_{imkt}^{WD} \leq Q_{mk}^{WD} Z_{mkt}^{WD} \qquad \forall\, m \in M. k \in K \text{ and } t \in T \qquad (60)$$

Equation (61) is for inventory balance at warehouses and shows that for each warehouse and each product in each time period, the available inventory is calculated by the available inventory in the previous period plus the quantity received from the plants in the current period minus the quantity sent to distribution centers.

$$q_{imt}^{W} = q_{imt-1}^{W} + \sum_{j\in J} x_{ijmt}^{PW} - \sum_{k\in K} x_{imkt}^{WD} \qquad \forall i \in I.\, m \in M.\, k \in K \text{ and } t \in T \tag{61}$$

Also, for each product, safety stock is defined in each time period at each warehouse (see equation (62)).

$$q_{imt}^{W} \geq SS_{imt}^{w} \sum_{s=0}^{t} W_{mst}^{W+} \qquad \forall i \in I.\, m \in M.\, k \in K \text{ and } t \in T \tag{62}$$

Now the proper auxiliary variables associated with the closing / remaining open status of the facilities should be set to confirm the accuracy of the opening and closing decisions in the model. Equations (63) to (66) show that during the whole planning period, firstly, if a warehouse was not initially open, it could only be opened at most once. Secondly, it also could be closed at most once if it was opened before. Finally, a warehouse cannot be opened and closed in the same time period.

$$\sum_{t\in\mathcal{T}} y_{mt}^{W+} \leq 1 \qquad \forall m \in M \tag{63}$$

$$\sum_{t\in\mathcal{T}} y_{mt}^{W-} \leq 1 \qquad \forall m \in M \tag{64}$$

$$y_{mt}^{W-} \leq \sum_{s=0}^{t-1} y_{mt}^{W+} \qquad \forall m \in M \text{ and } t \in T \tag{65}$$

$$y_{mt}^{W+} + y_{mt}^{W-} \leq 1 \qquad \forall m \in M \text{ and } t \in T \tag{66}$$

Equation (67) illustrates that if a plant was opened in the time period s then closed in the time period t, therefore all decision variables: opening (y_{ms}^{W+}), closing (y_{mt}^{W-}), and closing status (w_{mst}^{W-}) should be set to 1.

$$y_{ms}^{W+} + y_{mt}^{W-} \leq w_{mst}^{W-} + 1 \qquad \forall\, m \in M.\, s = 0. \ldots T-1. \text{ and } t = s+1. \ldots T \tag{67}$$

If only a closing decision was made, a closing status variable would be set to 1:

$$W_{mst}^{W-} \leq y_{mt}^{W-} \qquad \forall m \in M.\, s = 0. \ldots T-1. \text{ and } t = s+1. \ldots T \tag{68}$$

Also, an opening status variable (W_{mst}^{W+}) would be set to 1 if an opening decision was made:

$$W_{mst}^{W+} \leq y_{ms}^{W+} \qquad \forall m \in M.\, s \in \mathcal{T}. \text{ and } t = s+1. \ldots T \tag{69}$$

If a warehouse was opened in the time period s and is yet open in the time period t, in any of the periods in the internal s+1 and t, a closing decision is impossible:

$$W_{mst}^{W+} - y_{ms}^{W+} + \sum_{v=s+1}^{t} y_{mv}^{W-} \leq 0 \qquad \forall m \in M.\, s = 0. \ldots \mathcal{T}-1. \text{ and } t = s+1. \ldots T \tag{70}$$

3.6.2.3. At the distribution center level

Equations (71) and (72) show that the stored quantities in each distribution center for each product and time period must be within a pre-specified range.

$$\sum_{i\in I} q_{ikt}^{D} \leq D_{k}^{max} \sum_{s=0}^{t} W_{kst}^{D+} \qquad \forall k \in K \text{and } t \in T \tag{71}$$

$$\sum_{i\in I} q_{ikt}^{D} \geq D_{k}^{min} \sum_{s=0}^{t} W_{kst}^{D+} \qquad \forall k \in K \text{and } t \in T \tag{72}$$

Active distribution centers might send all or part of their products to customer zones as stated by equation (73).

$$\sum_{i\in I} \sum_{l\in L} x_{iklt}^{DC} \leq M \sum_{s=0}^{t} W_{kst}^{D+} \qquad \forall k \in K \text{ and } t \in T \tag{73}$$

Equation (74) shows that the total quantity sent by distribution centers to customer zones in each time period, if any, must satisfy the transport capacity.

$\sum_{i\in I} x_{iklt}^{DC} \leq Q_{kl}^{DC} Z_{klt}^{DC}$ $\forall k \in K.\ l \in L.\ \text{and}\ t \in T$ (74)

Note that customer zones do not hold inventory, so the total product received by each customer zone from the distribution centers has to be the same as the market demand (see equations (75)).

$\sum_{k\in K} x_{iklt}^{DC} = O_{ilt}.$ $\forall i \in I.\ l \in L.\ \text{and}\ t \in T$ (75)

Equation (76) is for inventory balance at distribution centers. It shows that for each distribution center and each product in each time period, the available inventory is calculated by the inventory available in the previous period, plus the quantity received from the warehouses minus the quantity sent to the customer zones.

$q_{ikt}^{D} = q_{ikt-1}^{D} + \sum_{m\in M} x_{imkt}^{WD} - \sum_{k\in K} x_{iklt}^{DC}$ $\forall i \in I.\ m \in M.\ \text{and}\ t \in T$ (76)

Also, at each warehouse, safety stock is defined for each product and time period (see equation (77)).

$q_{ikt}^{D} \geq SS_{ikt}^{D}$ $\forall i \in I.\ m \in M. k \in K.\ \text{and}\ t \in T$ (77)

Now the proper auxiliary variables associated with the closing / remaining open status of the facilities should be set to confirm the accuracy of the opening and closing decisions in the model. Equations (78) to (81) show that during the whole planning period, firstly, if a distribution center was not initially open, it could only be opened at most once. Secondly, it could also be closed at most once if it was opened before. Finally, a distribution center cannot be opened and closed in the same time period.

$\sum_{t\in \mathcal{T}} y_{kt}^{D+} \leq 1$ $\forall k \in K$ (78)

$\sum_{t\in \mathcal{T}} y_{kt}^{D-} \leq 1$ $\forall k \in K$ (79)

$y_{kt}^{D-} \leq \sum_{s=0}^{t-1} y_{ks}^{D+}$ $\forall k \in K.\ \text{and}\ t \in T$ (80)

$y_{kt}^{D+} + y_{kt}^{D-} \leq 1$ $\forall k \in K.\ \text{and}\ t \in T$ (81)

Equation (82) illustrates that if a plant was opened in the time period s then closed in the time period t, therefore, all decision variables: opening (y_{ks}^{D+}), closing (y_{kt}^{D-}), and closing status (w_{kst}^{D-}) should be set to 1.

$y_{ks}^{D+} + y_{kt}^{D-} \leq w_{kst}^{D-} + 1$ $\forall k \in K.\ s = 0. \ldots \mathcal{T} - 1. \text{and}\ t = s + 1. \ldots . T$ (82)

If only a closing decision was made, a closing status variable would be set to 1:

$w_{kst}^{D-} \leq y_{kt}^{D-}$ $\forall k \in K.\ s = 0. \ldots \mathcal{T} - 1. \text{and}\ t = s + 1. \ldots . T$ (83)

Also, an opening status variable (w_{kst}^{D+}) would be set to 1 if an opening decision was made:

$w_{kst}^{D+} \leq y_{ks}^{D+}$ $\forall k \in K.\ s = 1. \ldots \mathcal{T}. \text{and}\ t = s. \ldots . T$ (84)

If a distribution center was opened in the time period s and is yet open in the time period t, in any of the periods in the internal s+1 and t, a closing decision would be impossible:

$w_{kst}^{D+} \leq y_{ks}^{D+} + \sum_{v=s+1}^{t} y_{kv}^{D-} \leq 0$ $\forall k \in K.\ s = 0. \ldots \mathcal{T} - 1. \text{and}\ t = s + 1. \ldots . T$ (85)

4. Case study implementation and evaluation

4.1. Input parameters of the model

In order to evaluate the applicability and efficiency of the developed model presented in the previous section, we applied the data of a real company which is located in the UK as is shown in Figure 1 and studied by Longinidis and Georgiadis (2014) and Borges et al. (2018). Note that, because of some data incongruity and missing data, their case study could not be directly applied and we have considered the following assumptions regarding the missing information:

- This company has three plants in three different locations and four possible locations for warehouses and six potential locations for distribution centers.
- The facilities parameters are independent from each other
- Each plant is able to produce six of seven products within its limitations of production capacity. Each plant also holds about two times of the average annual demand as initial inventories.
- In each time duration, each warehouse and also distribution centers have an upper and lower bound handling capacity and need safety stock.
- Initial inventories are considered about two times of the average annual demand.
- Safety stock for each product at each facility is equal to the total quantity transferred from the facility during a period of 15 days.
- Product flows among plants, warehouses, distribution centers and customer zones have upper bounds.
- Prices and demands of products in each customer zone are known.
- The company has a 4-year planning horizon.
- Before the planning horizon, balance sheet data areintegrated into the optimization process.
- All tangible assets have been deprecated. Short-term liabilities (accounts payables and taxes of previous profits) should be paid in one year.

The real value of cash has been calculated, instead of considering it as a percent of net income.

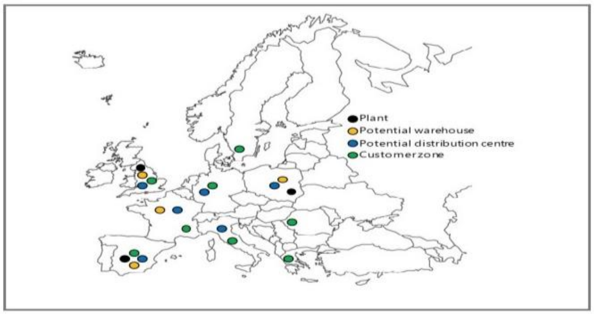

Figure 1. The case study supply chain network (Longinidis and Georgiadis, 2014)

4.2 Comparison between basic model and developed models

Now, to show the improvements in the proposed model, we compared the results of the basic model presented by Longinidis and Georgiadis (2014) with our developed models which have a new objective function, accurate calculations, and additional financial considerations. All the problems were solved by BARON solver in GAMS software on a personal computer with core i5 CPU 2.50 GHz and 8 GB of RAM on windows 8.

4.2.1. Basic model

The basic model was considered with the same decision-making assumptions and objective function presented by Longinidis and Georgiadis (2014). Its objective is to maximize the company's net created value which is measured by Economic Value Added (EVA) index.The model was solved and the total value created was 85,855,590 monetary units. The optimal results of the basic model will be used to compare them with results obtained from other developed models. In this way, it is possible to show the advantages of the proposed approach clearly.

4.2.2. The first developed model with new objective function

According to what explained in section 2, SVA is one of the most accepted methods to measure the value of a company. SVA by looking at the returns provided for its stockholders determines the financial value of a company. This measure is based on the view that the objective of company managers is to maximize the wealth of company stockholders. SVA calculates the shareholder value by deducting the value of long-term liabilities at the end of planning horizon from the value of the firm for the time period. In this study, the final value of the company is obtained by discounted free cash flow (DFCF) method with a fixed growth rate (0.5%).

Now, in the first stage of developing the model, Shareholder Value Analysis (SVA) is applied as an objective function in basic model. The model was solved and the total value created amountsis 86,855,590 monetary units.The optimal network configuration is shown in Figure 2. The total production quantities for the whole planning horizon is only 1407 units: plant 1 and plant 3 produce 809 and 598, respectively; plant 2 does not produce at all.Therefore, reducing inventory was clearly shown and had these results: i) decreasing production quantities to reduce the product quantities in stock. ii) More flow leads to opening a new distribution center to meet demands.In order to reduce the needs for working capital, SVA tends to reduce the inventory. Therefore, the produced quantity by SVA model is smaller than the EVA model.This feature of SVA model also makes a large number of flows between some facilities (warehouses, distribution centers, and customer zones). The total quantities transported from plants to warehouses for both models are compared in Table 2.

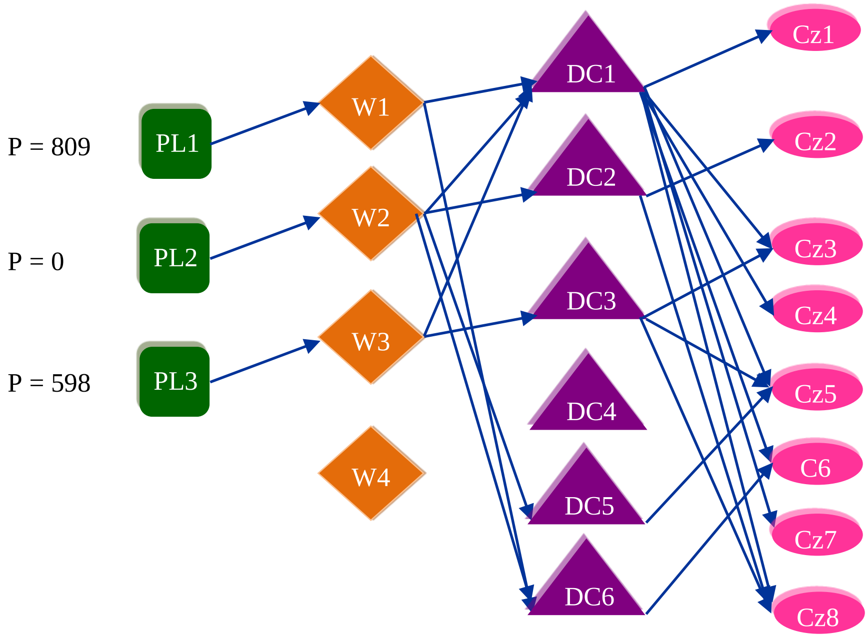

Figure 2. Network structure and produced products for the developed model

Table 2. Total products transported from plants to warehouses

	W1	W2	W3	W4
Plant 1	7901			
Plant 2		6210		
Plant 3			3502	

Developed model

	W1	W2	W3	W4
Plant 1	7471			
Plant 2		1498		
Plant 3			3201	

Basic model

According to Table 3, by SVA model, warehouse 1 receives more products supplying distribution centers 1 and 6. Similarly, warehouse 2 receives more quantity, therefore it supplies distribution centers 1,2, 5, and 6. But by EVA model, warehouse 2 just supplied distribution center 2.

Table 3. Total products transported from warehouses to distribution centers

	DC1	DC2	DC3	DC4	DC5	DC6
W1	5298					2543
W2	105	2303			508	3321
W3	161		3298			
W4						

Developed model

	DC1	DC2	DC3	DC4	DC5	DC6
W1	7471					
W2		1498				
W3			3201			
W4						

Basic model

As shown in Tables 3 and 4, by applying the model with SVA as the objective function, inventory was stored in five distribution centers (all distribution centers except 4), therefore, total flows between distribution centers and customer zones are much larger than total flows transported when EVA was the objective function.

Note that since distribution center 6 has the lowest inventory cost among others, it received most of the inventory transferred from warehouses to distribution centers. It receives 5864 units but it only supplies the customer zone 6 with 531 units and 5333 units are kept as inventory.Also, the model with SVA as the objective function tends to reduce the inventory quantities to decrease the need for working capital. Only 878 units stay at the plants as inventory.

Table 4. Total products transported from distribution centers to customer zones (SVA base model)

	CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8
DC1	1349		114	1672	123	904	1443	
DC2		1515						728
DC3			1498	346	620			816
DC4								
DC5					508			
DC6						531		
Developed model								

	CZ1	CZ2	CZ3	CZ4	CZ5	CZ6	CZ7	CZ8
DC1	1349			2018	1241	1413	1458	
DC2		1498						
DC3			1498					1559
DC4								
DC5								
DC6								
Basic model								

4.2.3. The Second developed model with new financial aspects

Now, in the second phase of model development, we add new financial aspects to the previous version of the model to make it similar to real conditions. These new features include the possibility of closing and opening facilities at any time period of the planning horizon, repayments obligation to the bank, adding the possibility of new capital entries from shareholders, and adoption of an accounts payable policy. To better understand the effect of these aspects, we explained them separately.

First, to test the possibility of closing and opening facilities at any time period, we considered two times of the establishment price of each facility as selling prices. The value created for shareholders is 87,397,697 monetary units which is 0.88% larger than the value created by the basic model that is the gains resulting from selling the plants. Then the new model with the obligation of bank repayments created 89,407,636 monetary units, which is 3.02% larger than the value created by the model with SVA asobjective function.The network structure remains the same. By repaying to the bank every year, long term debt is reduced and a lower amount is deducted from the free cash flow that was generated over the planning horizon, creating more value for shareholders.

Next, in order to consider an account payable policy, it is assumed that 60% of payments to suppliers are made in cash and 40% are made in credit.In this situation, the value created for shareholders is 88,549,322 monetary units, that is, 0.96% smaller. Because more amount of money (working capital) is needed to support operating expenses and pay suppliers, the free cash flow decreases and the value created is 858,314 monetary units lower.

Finally, we add the possibility of raising new capital from shareholders and also set a per- year limit of 60,000 monetary units for the new capital entries. This limit shows the maximum that shareholders are willing to invest in the company to receive dividends in the future. The new developed model was solved optimally and the value for shareholders increased to 92,460,308 monetary units, that is 3.18% larger than the value without these financial considerations created and 6.3% larger the value created by the basic model. Figures 3to 6 display the network structure during the planning horizon. As it can be seen, the flows between facilities and the quantities transported change during the time.

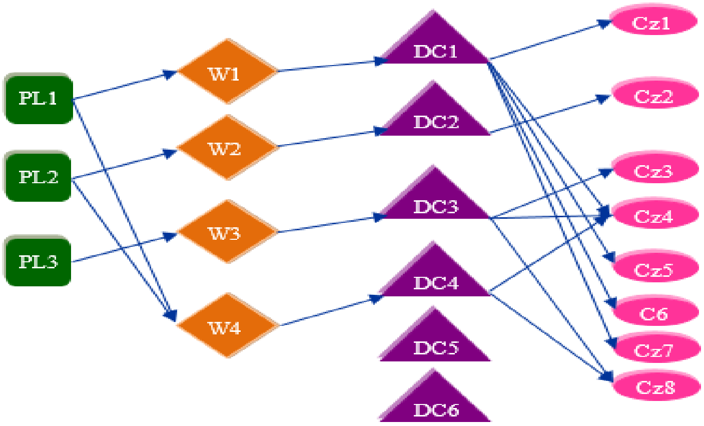

Figure 3. Network structure for the complete model in year 1 and for the developed model with new financial aspects

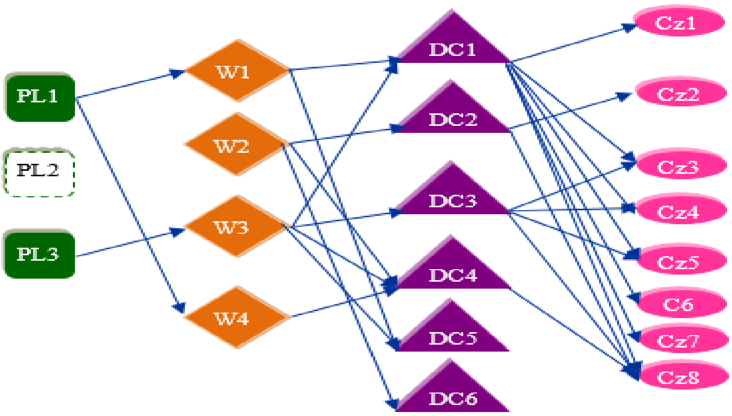

Figure 4. Network structure in year 2 and for the developed model with new financial aspects

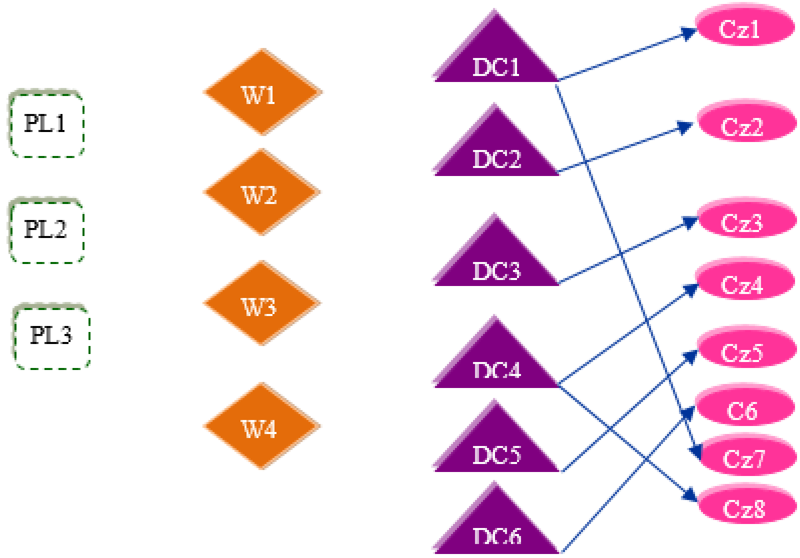

Figure 5. Network structure in year 3 and for the developed model with new financial aspects

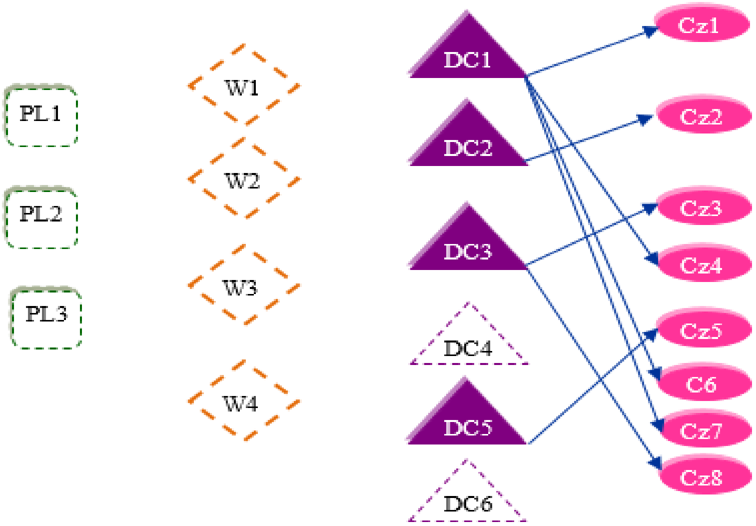

Figure 6. Network structure in year 4 and for the developed model with new financial aspects

According to Figures 3 to 6, plants only produce during the first two years and their total quantity is 1394 units.The total quantity produced by the SVA model is much lower than the quantity production when EVA was the objective function. Therefore, the need for working capital and payments to suppliers is smaller. These changes lead to an increase in the value created for shareholders.Also, by using EVA as the objective function, the value of the company improves by creating higher inventories (which are a part of current assets).

Plant 2 closes at the start of second year with a final inventory of 3341 units, reducing its initial inventory by 76%. Plant 1 and plant 3 are closed at the beginning of third year, with the final inventory of 1971 and 881 units. This means an inventory reduction of 245% and 285%, respectively.Note that products 2, 4, and 7 at plant 1 which were not sold within the planning horizon are considered as the final inventory. Also, products like 3 and 6 at plant 1 that were produced in the years 1 and 2, have no final inventory. As explained before, in accordance with the evolution of the number of flows among facilities, the product quantities transported from plants to warehouses increase from year 1 to year 2. Table 5 presented the operating costs (production, transportation, and inventory holding costs) that resulted from the decisions described above.As we can see, the largest portion of the operating costs is transportation costs (50.58%), then inventory holding costs (40.27%), and production costs (9.15%). There are production costs in the first and second years. Also, due to high inventory at the beginning of the planning horizon, there is no production in the years three and four.In these two years, from plants to warehouses and from warehouses to distribution centers, there are no transportation costs because plants are closed and the warehouses are not operating.As shown in Table 5, inventory costs decrease over time. The inventory costs at plants in years' tree and four refer to products that were already in inventory at the beginning of the planning horizon and the ones customers didn't request.It is important to note that although the final inventory at the distribution centers is equal to zero, there is an inventory cost since inventory is calculated based on its average during a year.

Table 5. Production, transportation, and inventory costs for year for the developed model with new financial aspects

	Year (1)	Year (2)	Year (3)	Year (4)	Total
Production cost	1013	90,102	0	0	91,115
Transportation cost	162,717	209,856	60,417	71,303	504,293
Inventory cost	141,402	109,542	89,502	60,991	401,437

According to financial decisions made by the final model, managers are provided with an accounts payable policy in Table 6. It shows that the company has enough cash (based on the initial balance sheet) and does not need bank loans. Therefore, all capital entries are captured from shareholders.As we can see, production costs by the developed model are low, since high levels of inventory and money are available for investment. Therefore, the company is in a good condition for repayments to the bank, decreasing debt and maximizing the value of the corporate which is measured by SVA.

Table 6. Financial decisions for each year for the developed model with new financial aspects

Financial decisions	Year (1)	Year (2)	Year (3)	Year (4)	Total
Loans	0	0	0	0	0
New capital entries	60,000	60,000	60,000	60,000	240,000
Investment	300,000	0	0	0	300,000
Repayments	540,000	270,000	135,000	67,500	1,012,500

4.3. Financial sensitivity analysis

In this section, the performance of proposed model was tested by changing some important financial parameters. These parameters are important because they are suggestive of the economic environment and in many cases are accepted conditions that the company has no impact on them. The cost of capital rate at time period t (R_t) is an important parameter.Also, one of the important financial parameters affecting the company's wealth is the tax rate (TR_t).Moreover, we selected the depreciation (DPR_{st}) rate as a financial parameter for the sensitivity test.

Table 7 presents the effects on the proposed model by changing these parameters from −15% to +15%. The results illustrate that the model with new financial considerations is resistant to the changes of these financial parameters.

Table 7. Sensitivity analysis of the objective function by changing in financial parameters

Parameter	Change (%)							
	-15	-10	-5	-2	+2	+5	+10	+15
Cost of capital rate at time period t (R_t)	105,947,496	101,350,940	96,869,752	94,204,964	90,717,780	88,114,172	83,796,384	79,838,788
Tax rate (TR_t)	99,756,840	97,326,664	94,896,184	93,435,236	91,484,468	90,020,784	87,580,196	85,139,760
Depreciation rate (DPR_{st})	93,832,792	93,377,628	92,919,880	92,644,304	92,275,780	91,998,608	91,534,324	91,070,724

4.4. Results and discussions

In the previous section, the optimal results of a basic model were used to compare them with the results obtained from other developed models to show the advantages of the developed models. We carried out two phases of development in order to improve the basic model: i) applying a new objective function, which maximizes the value of the company measured by the SVA method, ii) adding new financial aspects to the previous version of the model to make it more realistic.

In the first step, SVA was applied as a new objective function instead of EVA. The model with the new objective was solved and the total value created for shareholders was increased by 86,635,307 monetary units.

In the second step, the new financial aspects were integrated into the previous version of the model. The total value created by the complete version of the model was 92,460,308 monetary units which is 0.7% larger than the SVA obtained without financial aspects and 0.93% larger than the value created in the basic model. The main reasons for an increase in value creation for shareholders are due to new operational and financial aspects, which mainly show the possibility of closing facilities and bank-debt repayments. Bank repayments which reduce debt and new capital enables the company to choose better operational options. The value created by each model is reported in Table 8.

Table 8. Values obtained by each model

Model	Value created (Monetary units)
The Basic model	85,855,590
The first developed model with new objective function	86,635,307
The second developed model with new financial aspects	92,460,308

The main reasons for an increase in the value created of company are due to both operational and financial aspects such as the possibility of closing facilities and bank repayments.

In this study instead of EVA index, which is based on conventional accounting principles, SVA is applied as an objective function that is one of the most accepted methods of measuring how corporate performance relates to shareholder value. As mentioned before, the SVA for a company is calculated by adding the present value of cash flows to their terminal value, which represents the value of the company discounted at the proper cost of capital. The EVA for measuring a company's financial performance deducts its cost of capital from its net operating profit after taxes. As explained in the previous sections, since EVA is based on accounting principles, making unreasonable decisions is possible. For example, increasing current assets by higher inventories in order to make more EVA.

4.5. Managerial insight

As a result of decreasing profit margins and the competitive landscape, supply chain managers are forced to design and optimize the operation of their supply chain networks by considering operational and financial performance indexes at the same time. Therefore, they need comprehensive decision support models that track and measure the financial impact of their production and distribution decision by integrating various financial performances (Hamta et al., 2022). Moreover, this integration makes a "common language" between supply chain managers and financial managers and improves cooperation between them. This study suggests a mathematical programming decision model that considers the physical and financial aspects of a supply chain planning problem simultaneously. A deterministic Mixed-Integer Nonlinear Programming (MINLP) model has been developed to specify the number and location of facilities and the links between them. The model also determines the quantities to be produced, stored, and transported in order to meet customers' demands. According to financial decisions made by the model, managers are provided with an accounts payable policy since we consider the amount to invest, the source of the money needed (cash, bank loan, or new capital from shareholders), and repayments. It enables supply chain managers to take holistic decisions without underestimating the basic objective of a profit company which is the creation of value for shareholders measured by the SVA index. This objective indicates a satisfactory financial status in order to guarantee new funds from shareholders and financial institutions.

5. Conclusions and future research

Classically, supply chain networks are designed according to economic criteria such as cost minimization or profit maximization. Performance-based criteria such as service level or responsiveness maximization are also among the traditional objective functions adopted in the SCND models. Nowadays, other criteria including sustainability, energy, and financial factors, are employed in network design.

The importance of incorporating financial considerations into SCM has been reported many times in the literature. Many of the previous studies emphasize that strategic decisions such as supply chain decisions have a significant impact on shareholder value creation. Investment decisions also should be considered as critical inputs to financial planning. Since these kinds of decisions for supply chain networks play a key role in financial health of companies, therefore, financial considerations should also be regarded when modeling supply chains.However, studies on supply chain models integrating financial aspects are limited. In these studies, financial aspects have been considered as endogenous variables or known parameters in objective functions and constraints.

Regarding the significant importance of financial decisions, the primary goal of this study is to integrate financial decisions into the process of SCND, this study suggests a mathematical model that considers the physical and financial aspects of a supply chain planning problem, simultaneously. A deterministic Mixed-Integer Nonlinear Programming (MINLP) model was developed to specify the number and location of facilities and the links between them. The model also determines the quantities to be produced, stored, and transported in order to meet customers' demands as well as maximize the shareholder value measured by SVA method. In financial decisions, the amount of investment, the source of the money needed (cash, bank loan, or new capital from shareholders) and repayments to the bank were considered. To show the applicability and efficiency of the developed model, data of Longinidis and Georgiadis (2014) were used. The results show that with appropriate financial decisions, creating more value for the company and its shareholders is achievable. The model could be used by supply chain managers as an effective decision tool, supporting their decisions with figures and indexes convenient for financial managers. The major contributions of this study can be summarized as follow: This study presents a mathematical model to solve a SCND problem that considers tactical, strategic and financial decisions simultaneously.Maximizing the creation of economic value for shareholders measured by shareholder value analysis (SVA) as a new objective function instead of traditional approaches such as maximizing profits or minimizing costs.

The proposed model considers the amount of loan, bank repayment and new capital from shareholders as decision variables, therefore, it providesmanagers an accounts payable policy, instead of considering that all payments should be paid in cash. Previous studies of the literature consider them as parameters. At the strategic level, the model specifies the location of each facility. At the tactical level, it determines the products quantities to be produced and stored to satisfy customers' demand. Regarding financial decisions, the model specifies the amount of investment and their sources such as cash, bank debt or shareholders' capital as decision variables and it provides a repayment policy for managers.

Regarding the constraints, in addition to common operational constraints, lower limit and/or upper limit values for financial ratios in order to support the financial health of the corporation. To retain a better financial performance, the proposed model provides a balance among new capital entries, loans and repayment. With consideration of large cost of new capital entries, the model imposes upper bound on it and avoid an ever-increasing debt; it considers lower bound for bank repayments. Besides, these benefits of our model provide managers with an accounts payable guideline.Providing the possibility of opening or closing facilities in order to deal with market fluctuations during the planning horizon.

In contrast with basic models in previous studies which have too many assumptions, the presented model uses accounting principles with less assumptions that made it more realistic. For example, we use the net liabilities in the analysis of financial statements that balances bank loans and payments, determines the exact value of deprecation by knowing the lifetime of each asset in each time period, and applies real cash value instead of pre-determined proportion of profit.

However, this study is limited in several ways; firstly, the most limitation is that the model hasonly been tested on a case study. It would be better to demonstrate the efficiency of the proposed model, with more numerical experiments.Secondly, It is assumed that when a facility is opened it is immediately operational, which is hardly possible in a real-world situation.Finally, it is assumed a facility can only be supplied by the facilities in the previous echelon of the supply chain; however, real situations often consider the possibility of direct sales for instance sales from manufacturers to final customers.

In summary, it should be pointed out that our model can be expanded in the following directions: in order to make the model similar to real conditions, future studies can consider uncertainty in some parameters such as product prices and demand. Applying financial ratios as objective functions in the proposed model in order to find a way to increase and improve the firm soundness. The green supply chain with a closed-loop structure can be the other research trend for the model considering environmental, social, technological and economic facets; such facets can be included in the supply chain network design. The problem would get more complicated with such developments. Therefore, other solutions, such as metaheuristics, can be considered as other suggestions for futures research.

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Appendix

Table 9. Notations

Sets and Indices	
E	Resources of production indexed by e
I	Products indexed by i
J	Locations of plant, indexed by j
K	Locations of distribution center, indexed by k
L	Locations of customer zone, indexed by l
M	Locations of warehouse, indexed by m
T	Planning periods indexed by s and t
Parameters	

A_{jt}^{P}	Plant market price j during the time period t, with $j \in J$ and $t \in T$
A_{mt}^{W}	Warehouse market price m during the time periodt, with $m \in M$ and $t \in T$
A_{kt}^{D}	Distribution center market price k at time periodt, with $k \in K$ and $t \in T$
C_{jt}^{P+}	Cost for establishing a plant at location j during the time periodt, with $j \in J$ and $t \in T$
C_{mt}^{W+}	Cost for establishing a warehouse at location m during the time period t, with $m \in M$ and $t \in T$
C_{kt}^{D+}	Cost for establishing a distribution center at location k at time periodt, with $k \in K$ and $t \in T$
C_{jt}^{P-}	Cost for closing a plant at location j during the time period t, with $j \in J$ and $t \in T$
C_{mt}^{W-}	Cost for closing a warehouse at location m during the time periodt, with $m \in M$ and $t \in T$
C_{kt}^{D-}	Cost for closing a distribution center at location k during the time period t, with $k \in K$ and $t \in T$
C_{ijt}^{FP}	Fixed production cost for product i at plant j at time periodt, with $i \in I,\ j \in J$, and $t \in T$
C_{ijt}^{VPP}	Unit production cost for product i at plant j at time periodt, with $i \in I,\ j \in J$, and $t \in \mathcal{T}$
C_{ijmt}^{FTPW}	Fixed transportation cost of product i from plant j to warehousem at time periodt, with $i \in I,\ j \in J,\ m \in M$, and $t \in T$
C_{ijmt}^{VTPW}	Unit transportation cost of product i from plant j to warehousem at time periodt, with $i \in I,\ j \in J, m \in M$, and $t \in T$
C_{imkt}^{FTWD}	Fixed transportation cost of product i from warehousem to distribution center k at time periodt, with $i \in I,\ m \in M,\ k \in K$ and $t \in T$
C_{imkt}^{VTWD}	Unit transportation cost of product i from warehouse m to distribution center k at time periodt, with $i \in I,\ m \in M,\ k \in K$ and $t \in T$
C_{iklt}^{FTDC}	Fixed transportation cost of product i from distribution centerk to customer zonel at time periodt, with $i \in I,\ k \in K,\ l \in L$ and $t \in T$
C_{iklt}^{VTDC}	Unit transportation cost of product i from distribution center k to customer zonel at time periodt, with $i \in I,\ k \in K,\ l \in L$ and $t \in T$
C_{ijt}^{IP}	Unit inventory cost of product i at plant j at time periodt, with $i \in I. j \in J$ and $t \in T$
C_{imt}^{IW}	Unit inventory cost of product i at warehousem at time periodt, with $i \in I.\ m \in M.$ and $t \in T$
C_{ikt}^{ID}	Unit inventory cost of product i at distribution centerk at time periodt, with $i \in I.\ k \in K.$ and $t \in T$
D_{k}^{max}	Maximum capacity of distribution centerk, with $k \in K$
D_{k}^{min}	Minimum capacity of distribution centerk, with $k \in K$
I_{ijt}^{max}	Maximum inventory level of product i being held at plant j at the end of time periodt, with $i \in I.\ j \in J.$ and $t \in T$
O_{ilt}	Demand of product i from customer zone l at time periodt, with $i \in I, l \in L$, and $t \in T$
P_{ij}^{max}	Maximum production capacity of product i at plant j with $i \in I$ end $j \in J$
P_{ij}^{min}	Minimum production capacity of product i at plant j with $i \in I$ end $j \in J$
PR_{ilt}	Unit selling price of product i at customer zonel at time periodt, with $i \in I, l \in L$, and $t \in T$

Q_{im}^{PW}	Maximum limit of products that can be transferred from plant j to warehousem, with $j \in J$ end $m \in M$
Q_{mk}^{WD}	Maximum limit of products that can be transferred from warehousem to distribution center k, with $m \in M$ end $k \in K$
Q_{kl}^{DC}	Maximum limit of products that can be transferred from distribution centerk to customer zone l, with $k \in K$ end $l \in L$
R_{je}	Available quantity of resource e at plant j,with $e \in E$ and $j \in J$
W_m^{max}	Maximum capacity of warehousem, with $m \in M$
W_m^{min}	Minimum capacity of warehousem, with $m \in M$
SS_{ikt}^{D}	Safety stock of product i at distribution centerk, during the time period t with $j \in J$, $k \in K$, and $t \in T$
SS_{imt}^{W}	Safety stock of product i at warehousem, during the time periodt with $i \in I$. $m \in M$, and $t \in T$
CR_t	Lower bound for cash ratio during the time period t, with $t \in T$
CUR_t	Lower bound for current ratio during the time period t, with $t \in T$
CCR_t	Lower bound for cash coverage ratio during the time periodt, with $t \in T$
ATR_t	Lower bound for assets turnover ratio during the time period t, with $t \in T$
CP_t	Upper bound for new capital entries during the time periodt, with $t \in T$
$LTDR_t$	Upper bound for long-term debt ratio during the time period t, with $t \in T$
TDR_t	Upper bound for total debt ratio during the time periodt, with $t \in T$
ROE_t	Lower bound for return on equity ratio during the time period t, with $t \in T$
PMR_t	Lower bound for profit margin ratio during the time periodt, with $t \in T$
ROA_t	Lower bound for return on assets ratio during the time periodt, with $t \in T$
QR_t	Lower bound for quick ratio during the time periodt, with $t \in T$
ACDPl	Rate of accumulated depreciation of a facility opened at time periods and closed during the time period t, with s and $t \in T$
IR_t	Rate of Long-term interest during the time periodt, with $t \in T$
TR_t	Rate of tax at the time periodt, with $t \in T$
r_t	Rate of capital cost during time periodt, with $t \in T$
DPR_{st}	Rate of depreciation of a facility at the end of time periodt, with s and $t \in T$
ϱ_{eij}	Coefficient relating resource utilization rate of e to produce product i in plant j, with $e \in E$, $i \in I$, and $j \in J$
γ_t	Coefficient relating loans during the time periodt, with $t \in T$
μ_t	Coefficient relating payables outstanding at time periodt, with $t \in T$
α_t	Coefficient relating revenues outstanding at time periodt, with $t \in T$

Decisions and Auxiliary Variables

q_{ijt}^{P}	Inventory level of product i being held at plant j at time periodt, with $i \in I$, $j \in J$. and $t \in T$
q_{imt}^{W}	Inventory level of product i being held at warehousem at time periodt, with $i \in I$. $m \in M$. and $t \in T$
q_{ikt}^{D}	Inventory level of product i being held at distribution centerk at time periodt, with $i \in I$. $k \in K$. and $t \in T$
p_{ijt}	Product quantity i produced at plant j at time periodt, with $i \in I$, $j \in J$, and $t \in T$
x_{ijmt}^{PW}	Product quantity i transferred from plant j to warehousem in time periodt, with $i \in I$, $j \in J$, $m \in M$, and $t \in T$

x_{imkt}^{WD}	Product quantity i transferred from warehousem to distribution centerk in time periodt, with $i \in I$, $m \in M$, $k \in K$ and $t \in T$
x_{iklt}^{DC}	Quantity of product i transferred from distribution centerk to customer zonel during time periodt, with $i \in I.\ k \in K.\ l \in L$ and $t \in T$
y_{jt}^{P+}	$\begin{cases} 1 & \text{if a plant at location } j \text{ is opened at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $j \in J$ and $t \in T$
y_{jt}^{P-}	$\begin{cases} 1 & \text{if a plant at location } j \text{ is closed at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $j \in J$ and $t \in T$
y_{mt}^{W+}	$\begin{cases} 1 & \text{if a warehouse at location m is opened at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $m \in M$ and $t \in T$
y_{mt}^{W-}	$\begin{cases} 1 & \text{if a warehouse at location m is closed at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $m \in M$ and $t \in T$
y_{kt}^{D+}	$\begin{cases} 1 & \text{if a distribution center at location k is opened at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $\mathcal{K} \in K$ and $t \in T$
y_{kt}^{D-}	$\begin{cases} 1 & \text{if a distribution center at location k is closed at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $k \in K$ and $t \in T$
u_{ijt}	$\begin{cases} 1 & \text{if product } i \text{ is produced at plant } j \text{ at time period} t \text{ ;} \\ 0 & \text{otherwise.} \end{cases}$ with $i \in I.\ j \in J.$ and $t \in T$
z_{jmt}^{PW}	$\begin{cases} 1 & \text{if plant } j \text{ supplies warehouse m at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $j \in J.\ m \in M$ and $t \in T$
z_{mkt}^{WD}	$\begin{cases} 1 & \text{if warehouse m supplies distribution center k at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $m \in M.\ k \in K$ and $t \in T$
z_{klt}^{DC}	$\begin{cases} 1 & \text{if distribution center k supplies customer zone } l \text{ at time period} t; \\ 0 & \text{otherwise.} \end{cases}$ with $k \in K.\ l \in L$ and $t \in T$
w_{jst}^{P-}	$\begin{cases} 1 & \text{if plant j was opened at time period s and closed at time period t} \\ 0 & \text{otherwise.} \end{cases}$ with $j \in J$ and s and $t \in T$
w_{jst}^{P+}	$\begin{cases} 1 & \text{if plant j was opened at time period s and is still open at time period t} \\ 0 & \text{otherwise.} \end{cases}$ with k $j \in J$ and s and $t \in T$
w_{mst}^{W-}	$\begin{cases} 1 & \text{if warehouse m was opened at time period s and closed at time period t;} \\ 0 & \text{otherwise.} \end{cases}$ with $m \in M$ and s and $t \in T$
w_{mst}^{W+}	$\begin{cases} 1 & \text{if m was opened at time period s and is still open at time period t;} \\ 0 & \text{otherwise.} \end{cases}$ with $m \in M$ and s and $t \in T$
w_{kst}^{D+}	$\begin{cases} 1 & \text{if distribution center K was opened at time period s and is still open at time} \\ 0 & \text{otherwise.} \end{cases}$ with $k \in K$ and s and $t \in T$

w_{kst}^{D-}	$\begin{cases}1 & \text{if customer zone K was opened at time period} s \text{ and closed at time period} \\ 0 & \text{otherwise.}\end{cases}$ with $k \in K$ and s and $t \in T$
NCP_t	New capital entries from shareholders during the time period t, with $t \in T$
RP_t	Repaid amount to the bank during the time periodt, with $t \in T$
CA_t	Current assets during the time periodt, with $t \in T$
B_t	Bank debts during the time periodt, with $t \in T$
DPV_t	Depreciation value at time periodt, with $t \in T$
CS_t	Cost of sales at time period t, with $t \in T$
C_t	Cash during the time period t, with $t \in T$
FAI_t	Investment of fixed assets during the time period t, with $t \in T$
FAD_t	Divestment of fixed assets during the time periodt, with $t \in T$
IP_t	Interest paid(interest expense) during the time periodt, with $t \in T$
IC_t	Cost of holding inventory during the time periodt, with $t \in T$
LTD_t	Long-term debt during the time periodt, with $t \in T$
IV_t	Value of inventory at time periodt, with $t \in T$
NOI_t	Non-operating income during the time periodt, with $t \in T$
PC_t	Cost of production during the time period t, with $t \in T$
NFA_t	Net fixed assets during the time period t, with $t \in T$
REV_t	Revenues from sales during the time period t, with $t \in T$
TC_t	Cost of transportation during the time period t, with $t \in T$

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