An Optimization Model for a Retail Distribution Supply Chain Network Design – A Case Study

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Abstract

Delivering value to the consumer, allocating orders, and cost-optimization are all functions that the retail distribution supply chain performs with growing importance. As a result, businesses must embrace a comprehensive perspective of the entire network. These requirements have driven the modeling of supply chain network design from a retail standpoint. The study considers a multi-echelon network with several manufacturers, distributors, retailers, and customers while developing a mathematical model to minimize total costs. In addition, it uses secondary data from a Small and Medium-sized Enterprise in Vietnam, called the SME to improve its network. The findings are used for strategic and operational decisions, such as determining the number of facilities needed, optimizing total distribution costs, as well as resulting in a need for a strategic alliance. To our knowledge, this empirical study is one of the efforts to provide the door for more research on the adoption of a retail distribution supply chain network design.

Keywords
Multi-echelon, Network Optimization, Retail Distribution, Supply Chain Network Design.

1. Introduction

1.1 Theoretical Background
The Covid-19 epidemic is a notable example, which caused many retailers to experience supply shortages and demand increases never seen. It has never been more important to control supply and demand changes in retail distribution supply chains to create sustainable communities. Retailers, in fact, determine the pace of a distribution network and are crucial to community sustainability (Alikhani et al., 2019; Fernie & Sparks, 2014). Understanding how to design a retail distribution supply chain network has become a crucial problem (Alikhani et al., 2021; Ning & You, 2018). The Supply Chain Network Design (SCND) challenge requires making a variety of decisions, such as deciding the number, location, and capacity of facilities needed to deliver requested products to specific customers in a timely and cost-effective manner (Salehi Sadghiani et al., 2015).
To deal with problems from several key research areas such as SCND, supply chain contracts, logistics management, and production planning and scheduling, many mathematical models and algorithms are introduced such as mixed-integer linear programming (Sadeghi et al., 2023; Salehi Sadghiani et al., 2015), mixed-integer non-linear programming (You & Grossmann, 2008), multi-objective programming, fuzzy programming (Kazancoglu et al., 2021; Badhotiya et al., 2019; Vimal et al., 2019; Jindal & Sangwan, 2014), and heuristics/metaheuristic algorithms (Feizollahi et al., 2021; You & Grossmann, 2008). For example, Jindal & Sangwan (2014) suggested a fuzzy mixed integer linear programming model to select each facility location and allocation of parts, as well as the number of parts to maximize the organizational profit. Sadeghi et al. (2023) proposed a mixed-integer linear formulation for a dynamic modified stochastic p-median problem in a competitive supply chain network design. Besides, several studies developed multi-objective programming for facility location, and other supply chain problems to determine the

optimal solutions throughout the proposed supply chain network and increase responsiveness (Khan et al., 2021; Bal & Badurdeen, 2020; Yamchi et al., 2020; Hafezalkotob et al., 2016).

1.2 Problem Statement and Objectives

The SME operates in retail distribution with many points from North to South Vietnam. The firm is known as SME since its name and other information that would allow for its identification have been made anonymous. Since 2020, under covid-19 pandemic impacts and the increasing demand, the company is coping with distribution problems such as high costs of transportation, inventory, and rental; as well as considering more distribution depots and warehouses. Therefore, the main goal of the study is to develop an optimal distribution network for the SME with the best delivery routes to fulfill the demands of retailers while minimizing the total distribution costs. To achieve the goal, the following objectives are developed:

- Analyze the SCND in the SME retail distribution network.
- Develop a mathematical model for the SCND and deploy the CPLEX software to find the optimal solutions.

2. Research Methodology

2.1 Overview

Typical SCND decisions affect operational levels, such as inventory control policies, the choice of transportation modes and capacities, warehouse layout and management, vehicle routing, etc. Under a rigorous literature review, this study formulates a mixed integer linear programming (MILP) - a mathematical optimization model in which the variables are restricted to be integers, along with using secondary data of the SME to recommend the optimization of its operation. The proposed model will be solved by using the CPLEX tool which uses Optimization Programming Language (OPL). A great advantage of MILP is that there are a lot of solvers available (e.g., IBM Ilog CPLEX, GUROBI, XPRESS, SCIP). Especially, for small-to-medium-size problems, these solvers are surprisingly good at solving MILP problems without further knowledge from the user, making a combination of MILP and CPLEX a preferred choice (Ning & You, 2018; Salehi Sadghiani et al., 2015). The study can be categorized as applied research because they aim to strengthen the real SME's retail distribution network. The indices, parameters, and decision variables are respectively described in Table 2 and Table 3, follows that the objective functions, and constraints of the proposed model. The next subsection is outlined a brief profile of the case study.

2.2 Case Study of the SME

The old SME supply chain is the three-echelon network of factories-warehouses-retailers. Due to the demand increasing, the company is testing a four-echelon network described in Figure 1, which includes 2 factories located in the Central and the South of Vietnam, 2 current depots located in the North and the South, and 1 new depot opened in Central Vietnam, 20 warehouses (wholesalers), and 209 retailers (customers) in the country with 3 types of products which have the same dimensions. All the North-Central-South depots and wholesalers are rented from third parties logistics (3PLs). However, the company cannot control the costs, they coped with the increasing costs that negatively affect its profits. Therefore, this study aims to develop a mathematical model to test the SME network to find the most effective retail distribution supply chain network in considering which depots and warehouses should be rented to minimize total costs including transportation, inventory, and renting. Other objects including demands, capacities, and safety stocks are also considered in the model.

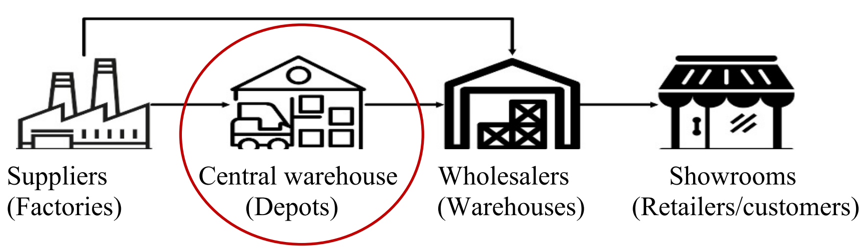

Figure 1: The Current Supply Chain Network of the SME

The SME has a transportation system (see Table 1) with the capacities of small and medium-sized trucks from 05 to 15 tons per truck, in diversified load per trip from 500 to 16,800 sets of products. The motorcycle also is used for trips from warehouses to retailers with about 10 sets per trip.

Table 1: Transportation System Description

Transportation	Vehicle	capacity load/trip
Supplier (factory) -> Central warehouse (depot)	Truck 15 tons.	~ 16,800 sets of products
Supplier (factory) -> Wholesale point (warehouse)	Truck 5 tons	~ 500 sets
Depot -> Wholesale point (warehouse)	Truck 5 tons	~ 500 sets
Warehouse -> Showroom (customer)	Motorcycles	≤ 10 sets

3. Research Model

3.1 Parameters, and Decision Variables

Table 2: Indices and Parameter Description

Group	Notation	Description
Indices	F	Set of factories, f: 1÷2
	D	Set of depots, d = 1÷3
	W	Set of warehouses, w = 1÷20
	C	Set of customers, c = 1÷209
	P	Set of products, p = 1÷3
	T	Set of months, t = 1÷12
Parameters	d_{pct}	Demand of product p from customer c, at time t
	cf_{pf}	Maximum capacity of factory f for product p
	cd_d	Maximum capacity of depots d
	cw_w	Maximum capacity of warehouse w
	$ctrs1_{fd}$	Transportation costs from factory f to depot d
	$ctrs2_{fw}$	Transportation cost from factory f to warehouses w
	$ctrs3_{dw}$	Transportation cost from depots d to warehouses w
	$ctrs4_{wc}$	Transportation cost from warehouses w to customers c
	chd_p	Inventory cost at depots d
	chw_w	Inventory cost at warehouse w
	hd_d	The rental cost of depot d
	hw_w	The rental cost of warehouse w
	ssd_{pd}	Safety stock for products p in depot d
	ssw_{pw}	Safety stock for products p at warehouse w

Table 3: Decision variables Description

Notation	Description
yd_d [0,1]	Binary variable, = 1 if depot d is rent, 0 otherwise
yw_w [0,1]	Binary variable, = 1 if warehouse w is rent, 0 otherwise
$n1_{fdt}$	The number of trucks transporting from factories f to the depots d at time t
$n2_{fwt}$	The number of trucks transporting from the factories f to the warehouses w at time t

$n3_{dwt}$	The number of trucks transporting from depots *d* to the warehouses *w* at time *t*
$n4_{wct}$	The number of motorcycles transporting from warehouse *w* to customer *c,* at time *t*
$q1_{pfdt}$	The total output of products *p* transported from factories *f* to depots *d* at time *t*
$q2_{pfwt}$	The total output of products *p* transported from factories *f* to warehouses *w* at time *t*.
$q3_{pdwt}$	The total output of products *p* transported from the depots *d* to warehouses *w* at time *t*.
$q4_{pwct}$	The total output of products *p* transported from warehouses *w* to customers *c*, at time *t*.
ID_{pdt}	The volume of products *p* inventory at the depots *d* at time *t*
IW_{pwt}	The volume of products *p* inventory at warehouses *w* at time *t*

3.2 Mathematical Model

Transportation cost =

$$\sum_{t\in T}\sum_{f\in F}\sum_{d\in D} ctrs1_{fd} * n1_{fdt} + \sum_{t\in T}\sum_{f\in F}\sum_{w\in W} ctrs2_{fw} * n2_{fwt} + \sum_{t\in T}\sum_{d\in D}\sum_{w\in W} ctrs3_{dw} * n3_{dwt} + \sum_{t\in T}\sum_{w\in W}\sum_{c\in C} ctrs4_{wc} * n4_{wct}$$

Inventory cost =

$$\sum_{p\in P}\sum_{d\in D}\sum_{t\in T} chd_p * ID_{pdt} + \sum_{p\in P}\sum_{d\in D}\sum_{t\in T} chw_w * IW_{pwt}$$

Renting costs =

$$\sum_{d\in D} hd_d * yd_d + \sum_{w\in W} hw_w * yw_w$$

Objective function: Min total costs = (Transportation costs + Inventory costs + Renting costs)

Subject to:

[1] At the time *t*, the sum of the transferred volumes from all warehouses *w* to customer *c* must meet customer demand for each product *p*.

$$\sum_{w\in W} q4_{pwct} \geq d_{pct} \;\forall p, c, t$$

[2] At the time *t*, the sum of the transferred volumes from factory *f* to all depots *d*, plus to all warehouses *w* must be smaller than the capacity of factory *f* for each product *p*.

$$\sum_{d\in D} q1_{pfdt} + \sum_{w\in W} q2_{pfwt} \leq cf_{pf} \quad \forall p, f, t$$

[3] At the time *t*, the sum of the transferred volumes of all products *p* from factory *f* to depot *d* must be full of a big truck capacity load.

$$\sum_{p\in P} q1_{pfdt} = 16800 * n1_{fdt} \quad \forall f, d, t$$

[4] At the time *t*, the sum of the transferred volumes of all products *p* from factory *f* to warehouse *w* must be full of a small truck capacity load.

$$\sum_{p\in P} q2_{pfwt} = 500 * n2_{fwt} \quad \forall f, w, t$$

[5] At the time *t*, the sum of the transferred volumes of all products *p* from depot *d* to warehouse *w* must be full of a small truck capacity load.

$$\sum_{p \in P} q3_{pdwt} = 500 * n3_{dwt} \quad \forall d, w, t$$

[6] At the time *t*, the sum of the transferred volumes of all products *p* from warehouse *w* to customers *c* must never be greater than the motorbike capacity load.

$$\sum_{p \in P} q4_{pwct} \leq 10 * n4_{wct} \ \forall w, c, t$$

[7] At the time *t*, if there is a shipment from the factory *f* to depot *d*, the depot must be rented.

$$q1_{pfdt} \leq yd_d * M \quad \forall p, f, d, t$$

[8] At the time *t*, if the depot *d* is rented, the inventory must be smaller than the capacity of the rental depot.

$$ID_{pdt} \leq yd_d * cd_d \ \forall p, d, t$$

[9] At the time *t*, if there is a shipment from factory *f* to warehouse *w*, the warehouse must be rented.

$$q2_{pfwt} \leq yw_w * M \quad \forall p, f, w, t$$

[10] At the time *t*, if there is a shipment from the depot *d* to warehouse *w*, the warehouse must be rented.

$$q3_{pdwt} \leq yw_w * M \quad \forall p, d, w, t$$

[11] At the time *t*, if the warehouse *w* is rented, the inventory must be smaller than the capacity of the rental warehouse.

$$IW_{pwt} \leq \ yw_w * cw_w \ \forall p, w, t$$

[12] At the time *t*, the inventory of product *p* at depot *d* is equal to the previous inventory of the product at the depot, plus the sum of the transferred volumes of the product from all factories *f* to the depot, minus the sum of the delivered volumes of the product from the depot to all warehouses *w*.

$$ID_{pdt} = \ ID_{pdt-1} + \sum_{f \in F} q1_{pfdt} - \sum_{w \in W} q3_{pdwt} \quad \forall p, d, t$$

[13] At the time *t*, the inventory of product *p* at warehouse *w* is equal to the previous inventory of the product at the warehouse, plus the total of the sum of transferred volumes of the product from all factories *f* and all depots *d* to the warehouse, minus the sum of the delivered volumes of the product from the warehouse to all customers *c*.

$$IW_{pwt} = \ IW_{pwt-1} + \sum_{f \in F} q2_{pfwt} + \sum_{d \in D} q3_{pdwt} - \sum_{c \in C} q4_{pwct} \ \ \forall p, w, t$$

[14] At the time *t*, the inventory of product *p* at depot *d* is greater than the safety stock of *p* in that depot.

$$ssd_{pd} \leq ID_{pdt} \quad \forall p, d, t$$

[15] At the time *t*, the inventory of product *p* at warehouse *w* is greater than the safety stock of *p* in that warehouse.

$$ssw_{pw} \leq IW_{pwt} \ \ \forall p, w, t$$

4. Data Collection and CPLEX Running

From the above investigation, a MILP model is outlined that orients for data collection which is one of the important steps to modify the proposed model closer to the scenarios of the SME network and then codes them into the CPLEX solver for calculation.

Collected data from the Accounting Department includes capacities of 2 factories, 3 depots, and 20 warehouses; demands of 209 customers for 3 products for 12 months; holding and hiring costs of all depots and warehouses, as well as their safety stocks; especially, transportation costs matrices from factories to depots, factories to warehouses, depots to warehouses, and warehouses to customers.

Figure 2 illustrates the CPLEX calculation for the modified network model that produces a total cost of VND 22,250,892,500. Results and discussion are described in the next section.

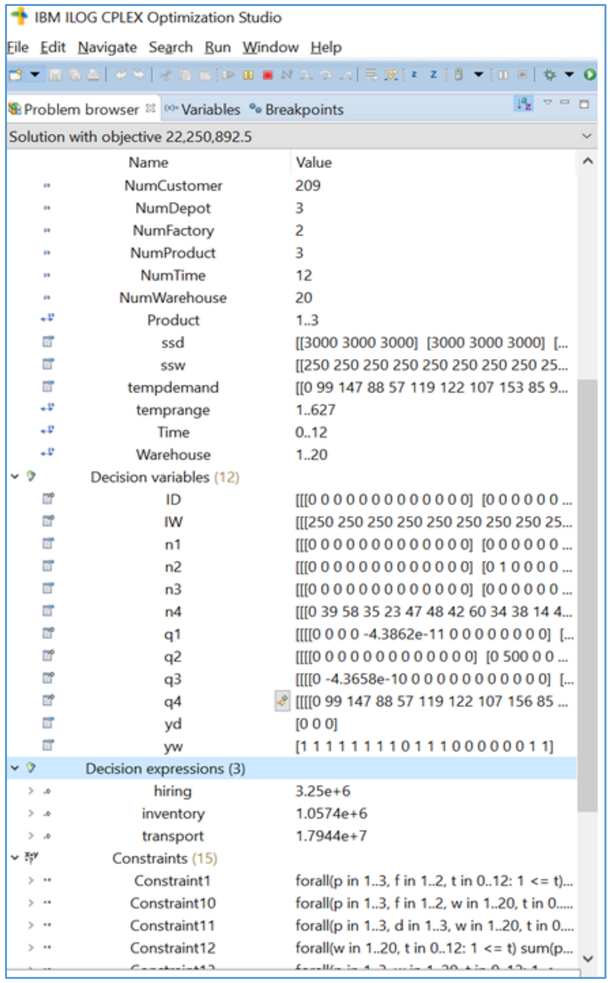

Figure 2 – A screenshot of the total cost calculation for a modified model

5. Results and Discussion

To test the main aim of the study, the author develops 3 scenarios of supply chain networks with specific assumptions below (see Table 4). The scenarios are evaluated by their total costs.

Table 4: Testing scenarios

Scenarios	Description	Total costs (VND)
1. The current network	2 factories, 3 depots, 20 warehouses, and 209 customers	35,540,500,000
2. The old network	2 factories, 20 warehouses, and 209 customers	26,645,159,250
3. A modified network	2 factories, 0 depots, ≤ 20 warehouses, and 209 customers	22,250,892,500

Scenario 1: The current network is presented in Figure 1 where the SME expands to the four-echelon network, in which the company considers all 3 depots and 20 warehouses introduced by the 3PLs.
Obviously, with current needs, the rental costs are too large and dominant, the total costs are up to VND 35,540,500,000.

Scenario 2: The old three-echelon supply chain network (see Figure 3).

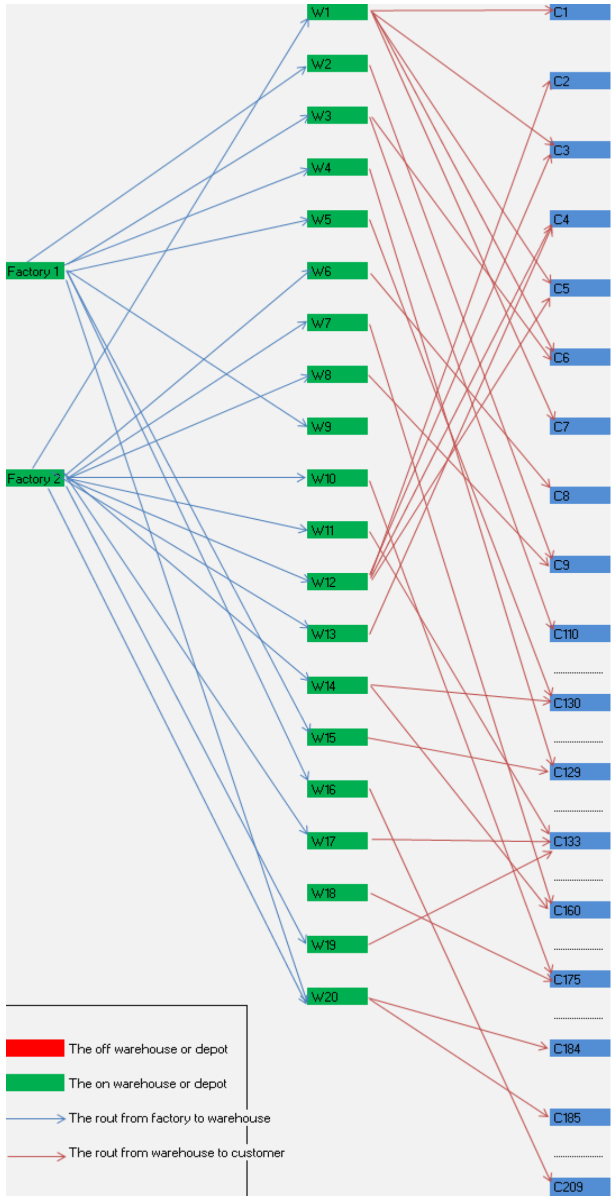

Figure 3 – The old three-echelon supply chain network

Figure 3 illustrates the old SME supply chain network, in which, the company uses 2 factories for packaging, sorting, and product quality evaluation. A total of 20 warehouses are rented, providing demands of 209 customers across the country. With this model, the total costs are VND 26,645,159,250. At the time, the company coped with uncontrollable implicit costs.

Scenario 3: The modified supply chain network with 2 factories, 0 depots, less than 20 warehouses, and 209 customers (see Figure 4).

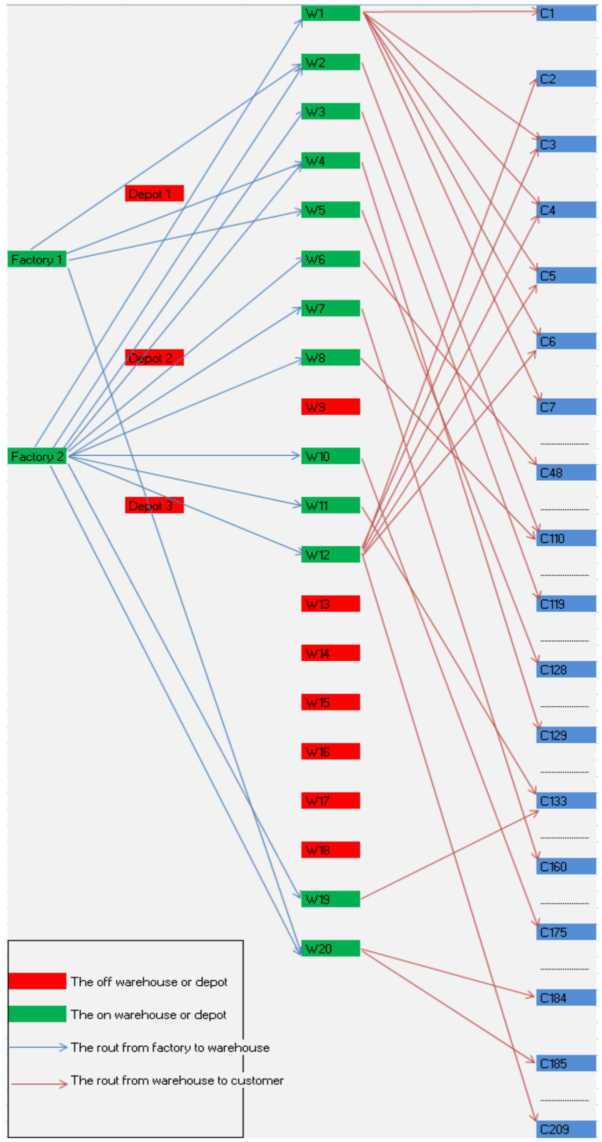

Figure 4 – A modified supply chain network model

In this case, the mathematical model solved by the CPLEX software produced the most minimal total cost of VND 22,250,892,500 (see Figure 2). Compared with the above two in the cost aspects, scenario 3 produces the most optimal supply chain network and gives the most effective results for the distribution system of the SME at the time. Moreover, the results of the study suggest that the SME should decide to close 3 depots and 7 warehouses, especially, since decisions are not only considering the number of closed warehouses but also their location such as warehouse 9 and warehouses 13 to 18 (see Figure 4).

Besides, scenario 2 can be seen as a suboptimal model which the company developed in the early periods with only a few warehouses and then gradually hire more warehouses based on the increasing number of customers. At the time, the SME should be considered more about hiring the depots and warehouses, because the costs of hiring are dominated as in scenario 1.

The findings of the study also recommend that the SME should focus more on developing strategic alliances such as 3PLs or 4PLs selection, distribution integration, and retailer-supplier partnerships to build a certain level of trust in the collaboration of supply chain network so that getting more advantaged policies such as a cheapest and long-term rental quotation, etc.

6. Conclusion, Limitations, and Future Research

The study examines the SME operations in Vietnam by using the MILP method and CPLEX tool. The results are useful for the SME to consider strategic and operational decisions in the distribution network design, such as figuring out how many facilities are required and how to optimize total distribution costs. This SCND optimization model not only helps the SME at that time but also be applied in the future if the company focuses more on long-term strategies to develop effective strategic alliances to cope with customer demand changes. With the MILP method and CPLEX OPL solver, users will be exposed to a simple, easy-to-customized method and programming language. On the other hand, the MILP method will be more accessible for those with more work experience, they can model based on very practical constraints, and the giving outcomes are also as good as other methods. This paper not only confirms the effectiveness of the mathematical model in designing supply chain networks for the SME retail systems but also desires to introduce new methods and tools to small and medium-sized companies in Vietnam.

Limitations and Future Research Direction

Generally, many retail distribution companies in Vietnam, especially small and medium-sized companies, build a supply chain network based on experience when started their business. This caused uncontrollable implicit costs, time, and distance leading to order lasting, cost increases, etc. The SME is one such company, a mathematical model, and a technical tool to improve the business are needed. However, the model still has limitations, for example, the author should investigate more into business processes to modify and add more realistic and effective constraints, and other variables such as labor costs, as well as relevant data.

Mathematically, if there are more constraints, the algorithm will be easier, and the program will produce faster, more optimal results. However, there is always a contradiction in the adoption of mathematical models for practical problems, therefore, there should be coordination between model builders and companies. In summary, future research is directed by limitations, in which more data analysis and consideration of both internal and external factors would improve the study.

Acknowledgments

The author is thankful to the Internal Grant Agency of FaME TBU in Zlín no. IGA/FaME/2022/005 for financial support to carry out this research.

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