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Article

Facility Location Placement Optimisation for Bagged Cement Distribution During the COVID-19 Pandemic

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Abstract. This study was based on a challenge that one of Thailand's cement companies encountered in 2021 as a result of fierce competition in the Northeastern region and falling market share during the COVID-19 pandemic. Without a doubt, the management of supply chains played an essential role in this issue. As a result, this research addressed the company's distribution strategy by attempting to determine a new location for the distribution centre to achieve two conflicting objectives at the same time, namely, minimising total transportation cost and maximising service level (delivery lead time reduction). For the problem at hand, a linear programming model was developed. Once different options were identified, the pros and cons of each approach were evaluated, and then the distribution strategy was altered to meet the actual conditions. It was discovered that changing distribution centres in some locations was a successful strategy for shortening delivery lead times with an opportunity to achieve a 22% improvement in service level while still controlling transportation expenses prior to arriving at the end customers not beyond the target at 15% increased from the current strategy.

Keywords: Facility location, distribution centre, cement, linear programming, COVID-19.

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1. Introduction

1.1. Supply Chain Management

The supply chain involves converting raw materials, producing final products, and distributing them to end customers in different locations. The operations start from the sourcing process, inbound transportation, storage and material handling, inventory control, warehousing, and distribution (Zijm et al., 2019) [1]. The main objective of the supply chain is to fulfil a customer request with the maximum net value generated. The difference between the value of a product to the end customer and the total cost in supply chain activities is considered as net value or supply chain surplus.

A successful supply chain provides a high level of service while keeping minimum cost. To achieve successful supply chain operations, many decisions are required to manage the information flow, physical products, and cost, which can be categorised into three phases. For long-term planning, the supply chain strategy or design is the decision for the next several years regarding resource allocation, distribution network (locations and capacities of production or storage), transportation modes, and information system. In the mid-term strategy, supply chain planning is developed to maximise the supply chain surplus by generating a demand forecast, considering supply locations to each market, establishing inventory policies, and defining service levels. The decision in this phase must include the constraint of uncertain demand and market competition to optimise the performance. Finally, short-term strategy or supply chain operation is the decision to handle individual customer orders to ensure the availability of products for incoming orders (Chopra, 2019) [2].

One of the main contributions to achieving enterprise efficiency is supply chain activities which can increase the company's competitiveness by reducing costs and improving the service level. There are two widely recognised schemes to improve supply chain performance consisting of the appropriate design of supply chain networks and effective resource allocation. Supply chain optimisation is the balance of many decisions on distribution centres, network connectivity, inventory policies, and other aspects that impact customer satisfaction, company profitability, and competitiveness in the market (Pistikopoulous et al., 2008) [3].

The popular technique for supply chain optimisation is the application of operations research on facility location problems. The objective is to consider facility establishment based on demand consumption and other relevant constraints. There are many types of applications depending on the objective and decision variables. Facility location is one of the most critical and difficult activities for the supply chain since it requires high investment and is unable to change in a short period. A supply chain network is designed on each location's storage location, transportation-related activities, facilities capacity, and distribution area. Some network design models aim to optimise multi-objectives. For example, minimising distribution costs and minimising time to market by ensuring product availability at the end-customers (Farahani and Hekmatfar, 2009) [4].

1.2. Cement Distribution Network in Thailand

Regarding the case of a big cement manufacturer in Thailand (sometimes referred to as Company A), the market share of bagged cement in the Northeast region decreased from 44% in the first half of 2021 to 30% in the 3rd quarter. Similar to other industries, top management realised that many factors might cause decreasing demand, including the COVID-19 pandemic (Suranuntchai and Chutima, 2023) [5]. As a result, the company needed to improve its performance in terms of product quality, business strategy, and distribution network. As a member of the supply chain department, this research was mainly focused on the distribution network, particularly transportation cost and service level (delivery lead time). Although the company was offering the lowest transportation cost in the market, its delivery lead time was still longer than its competitors.

Table 1 shows the comparison of transportation cost and delivery lead time in the Northeast region among the top-three companies in Thailand. The company delivered bagged cement to customers at a 6-15% lower than the average transportation cost. However, its delivery lead time was approximately 35% longer than the other two rivals. Moreover, its competitors delivered the product to all provinces in the Northeast region within one day, leading to high customer satisfaction. As a result, to survive in the long term, the company needs to increase its competitiveness by improving the delivery lead time while controlling transportation costs at the same levels as its competitors.

Table 1. Transportation cost and delivery lead time of bagged cement in the Northeast of Thailand.

Province	Est. Volume (Tons/year)	Distance (KM)	Est. Transportation Cost (THB/ton)			Delivery Lead Time (Day)		
			A	B	C	A	B	C
Amnat Charoen	10,000	456	466	621	669	2	1	1
Bueng Kan	10,000	621	608	787	796	2	1	1
Buri Ram	175,961	281	284	284	284	1	1	1
Chaiyaphum	3,948	202	242	204	204	1	1	1
Kalasin	38,828	388	404	392	392	1	1	1
Khon Kaen	197,664	318	350	481	420	1	1	1
Loei	105,077	435	414	439	439	1	1	1
Maha Sarakham	95,310	342	360	345	345	1	1	1
Mukdahan	86,235	523	531	688	688	2	1	1
Nakhon Phanom	16,820	607	599	773	782	2	1	1
Nakhon Ratchasima	426,724	126	173	127	127	1	1	1
Nong Bua Lam Phu	52,068	402	413	406	406	1	1	1
Nong Khai	5,123	497	498	657	671	2	1	1
Roi Et	14,274	365	377	529	529	2	1	1
Sakon Nakhon	34,052	517	514	682	691	2	1	1
Si Sa Ket	52,117	442	421	606	606	2	1	1
Surin	71,211	328	331	491	331	1	1	1
Ubon Ratchathani	158,271	500	477	665	465	2	1	1
Udon Thani	80,413	437	452	597	450	2	1	1
Yasothon	13,035	402	415	566	566	2	1	1
Total	**1,647,131**	**327**	342	403	363	1.35	1	1

Since the company has established internal key performance indicators (KPIs) to control its business performances (Fig. 1), the three main KPIs of the logistic function are categorised as quality, time, and cost. The company can control the damage and loss of product within the target for quality indicators, less than 0.25% of the total quantity. This means no problem is observed in transportation and warehouse operations. In 2021, the company had worse KPIs than the previous year in terms of time and cost, which stated that more than 96% of total shipments must be delivered to the customers before their requested times. However, the company failed to achieve the target in 2021 (achieving only 95% on-time delivery). Several factors could impact on-time performance, including pick-up, loading, and transport time. It was believed that by reviewing and designing a new distribution network, the company could shorten transit time since the depots could be located near the customers' locations. However, the indicator that must be maintained at the current level is the transportation cost. The company achieved the KPI by controlling it for less than 345 THB/ton. Even though the cost is manageable, a higher service level may come along with a higher price, which must be considered in the design of a new distribution network for the company.

Category	KPI	2020	2021 (YTD – Aug)	Comparison
Quality	Damage and loss			2021: 0.08%; 2020: 0.07%
Time	On-time delivery			2021: 95%; 2020: 96%
Cost	Transportation Cost (THB/Ton)			2021: 331; 2020: 325

Fig. 1. Logistics key performance indicators of the cement company.

1.3. Problem Statement

Due to the COVID-19 situation in Thailand in 2020-2021, the bag cement market had intense competition for market share acquisition, especially in the Northeastern region of Thailand. Major competitors of the company provided faster delivery service by distributing products to the end customers from their distribution centres located in many provinces in the same region. The company desired to increase its competitiveness to increase sales volume and profits from selling products during the COVID-19 pandemic. Therefore, when comparing the service level and transportation cost with its competitors, the company established the allowance policy to increase the level of competitiveness in service by developing the best level of service with increased costs not exceeding 15% from the current value so that the company could still maintain costs and profits from selling products at a similar level. The company admits multiple objectives in designing a new outbound distribution to optimise the delivery lead time and transportation costs. Moreover, the distribution starts with transferring the stock from the production plant to depots and distributing it to the dealers (Fig. 2).

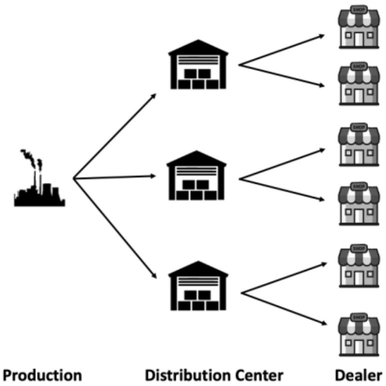

Fig. 2. The outbound distribution process flow.

In conclusion, this research aims to solve the problems of the cement company by considering the strategic location for distribution centres to reduce the delivery lead time which increases service levels or customer satisfaction to the same level as competitors in the market. At the same time, the increase in overall transportation cost should not exceed 15% from the current, which is an acceptable cost that the company can manage their overall performance.

The remaining sections are organised as follows: Related literature is reviewed in Section 2. Section 3 explains the research methodology. The experimental results are illustrated in Section 4. Finally, the concluding remarks are given in Section 5.

2. Literature Review

In a large organisation, supply chain management plays an important role in the business in cost and operational dimensions. The competitive supply chain can contribute to the lower product price, which the company might offer special promotions or discounts to compete with other companies. The strategic decision has a different impact depending on the industry and organisation structure. Outbound logistics is one of the significant elements in the supply chain that can improve for more effective operation and competitive cost. However, other performances, such as service level and customer satisfaction, must be considered in the strategy to ensure that it does not negatively impact the customer perspective. The literature review focuses on distribution network optimisation to improve the overall network footprint. An effective distribution network can contribute more margin to the company as it can save a major portion in product cost.

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2.1. Cement Industry Background

The cement industry is one industry that significantly affects the country's development. This is because many infrastructures consume huge amounts of cement for construction. The cement business plays an important role as the foundation of many industries. The number of cement consumption continuously grows, especially in developing countries with many mega projects such as roads, airports, railways, office buildings, and accommodation. The demand for cement is increasing every year, which is in line with the development plan to support the economic growth of each country.

The supply chain has many processes, from inbound logistics to feeding raw materials into production until outbound logistics deliver the final product to the end customer. Each step will have a storage location to stock products or materials ready for the following process (Fig. 3).

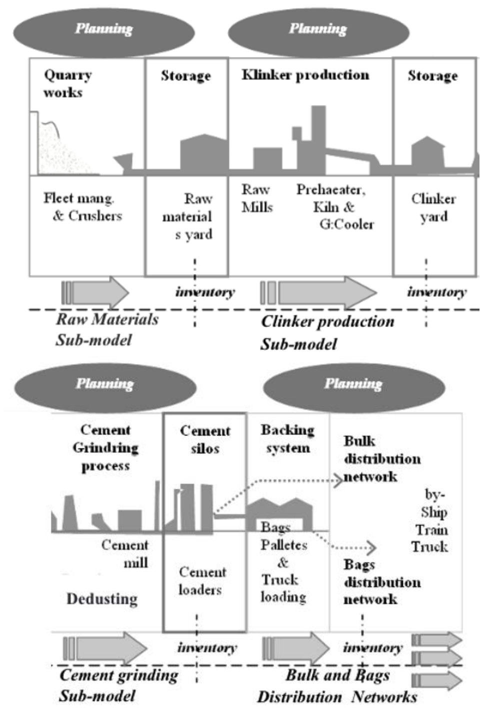

Fig. 3. Cement supply chain model (Noche and Elihasia) [6].

For cement distribution, there are two different methods to deliver the product to retailers or end customers: bagged cement and bulk cement. Bulk cement requires a specific truck type and equipment to unload to the cement silo, so they must invest massive amounts of money for the facility, and difficult to move the distribution centre to other locations. On the other hand, bag distribution is more flexible since it can utilise a regular fleet, and the warehouse facility does not require a high investment. Outbound logistics responsibilities start from receiving the product from manufacturer plants, transporting it to the warehouse or distribution centre, and delivering it to their retailers or customers in each region.

2.2. Supply Chain Optimisation

Damani (2017) [7] argued that the cement industry is a push market since the influencer (salesman) will try to sell the available product on the shelf to customers who do not differentiate between different brands. Therefore, the manufacturer must consider putting the production or distribution centre close to the end customer as much as possible. The cement price cost structure includes components such as manufacturing, discount, VAT, and freight. Freight cost is around 15-25% of the total cement price depending on transportation mode and distance from the production. This is the reason that supply chain network design is important to the revenue of a business. Tsiakis et al. (2001) [8] explained that supply chain management aims to deliver the right product in the right quantity at the right time to the right place. All activities should spend the minimum cost but still achieve the service level to satisfy customers. Many methods are used to design the distribution network, but the most popular solution to optimise the problem is linear programming to minimise cost.

2.3. Distribution Network Design

Based on a service provided by a supply chain consulting firm specialising in supply chain optimisation design, Establish (2020) [9] described Distribution Network Design as locating a facility that delivers products from factories to customers, including the distribution flow. The design methodology, The Establish Way™, outlines eight steps from project kick-off to implementation phase for companies looking to change their supply chain strategies to increase efficiency. The design aims to minimise costs while providing the highest levels of customer service, flexibility, and resilience to enable businesses to operate efficiently and survive in changing situations. The 8-step methodology is a process for large organisations in general, which usually kicks off the project. Hence, stakeholders are aware of the initiative's goal, what to do, and the scope covered by that project. After that, the data is collected and validated, including information on current operations that will be used as a baseline to compare what has changed after implementing the new strategy. Then go into the calculation process by using the centre of gravity to find the appropriate point before calculating in various ways to get a conceptual model, which is the answer that will be applied. However, before the actual implementation, the results must be analysed as to the benefits and what will happen from the changes to recommend to the stakeholders for the alignment and mutually agree on the timeline or steps for implementation.

2.4. Mathematical Model for Facility Location Problem

Tadei et al. (2009) [10] described that the transhipment problem consists of 2 parts, i.e. from origins to transhipment facilities and from transhipment facilities to final location (end customer). The total distribution network cost includes fixed costs and variable costs of facility, operation, and transportation.

Adeleke and Olukanni (2020) [11] argued that the facility location problem (FLP) is an essential part of logistics management which considers opening a warehouse (depot) in a suitable location for the lowest cost. The facility location problem helps improve the material flow and utilise the selected facilities. This model can solve the optimal solution, but it will require more time to generate the result if the size of the problem is increased.

Cantlebary and Li (2020) [12] stated that the facility location problem (FLPs) theory consists of Capacitated and Incapacitated FLPs. The first, or a capacitated facility problem, is to constrain both transportation and each facility to have a limited capacity, such that sometimes the demand in one area may not be served by the capacity of a single facility. On the other hand, an uncapacitated facility problem is to assume that transportation and facility have unlimited capacity, making this type of solution the most cost-effective solution as it usually considers the nearest location.

Sridharan (1995) [13] discussed the capacitated facility location problem (CFLP), which sets the capacity of each location to determine how many facilities can be stored at each location, including the capacity of the destination refers to the amount of customer demand for the product. The main objective of this approach is to minimise the overall cost of setting up facilities and satisfying customer demand.

Corberan et al. (2020) [14] introduced the concept of the facility location problem with capacity transfer (FLPCT), which means that the transfer of goods from one facility to another can only be done with a specified finite quantity. In this way, it helps to find a better solution in two aspects. The authors described expected benefits in the first point as reducing duplication of shipments when supply exceeds demand and one customer location might be served by more than one origin. Determining the capacity of the transport will allow the calculation to try to make efficient use of the limited capacity, resulting in lower overall shipping costs. Another case of determining the capacity transfer is a calculation where supply is less than demand, and the answer may be to open multiple facilities to meet the total demand without using the available capacity of the existing facility. By defining the capacity transfer, the result is recommended to transport goods between facilities to meet customer demand in each area which is beneficial to optimise facility set-up cost.

Sakchanalaya (1999) [15] has described in the research that it is most similar to the facility location placement for cement distribution centres in Thailand. The study used linear programming to calculate the result and refined the outcome by using criteria to filter responses hierarchically based on topics gathered from relevant departments within the organisation (Analytic Hierarchy Process), such as customer service level, delivery capability, and vehicle availability. Then give a score in each sub-topics based on the reviewer's opinions and choose a distribution point from the program's results that calculated the changes using the specified criteria.

The recent cement distribution network studies published in 2015-2021 (Table 2) have the same objective to minimise supply chain cost or maximise profit. From 5 studies, most of the article has been researched in Southeast Asia, with only one study from Africa. There is a gap in the previous research in that studies have not mentioned service level (delivery lead-time), and most of the studies are in the same area (only three countries). Another gap for further studies (Table 3) is the objective to improve service level by adding the objective function to maximise service level (minimise delivery lead time).

Table 2. Recent supply chain network design studies during 2015-2021.

Authors	Country	Objective	Calculation Parameters
Lwin et al. (2015) [16]	Myanmar	Maximise the profit	Revenue, cement demand, production capacity, cost (fixed, transportation, inventory)
Nooranda, and Vanany (2021) [17]	Indonesia	Minimise supply chain costs	Production capacity, cement demand, all cost (production, shipping, transportation, fixed, administration)
Pamungkas et al. (2020) [18]	Indonesia	Maximise total operating income of the supply chain	Market size, market share (possible demand), production capacity, product price, operating income, cost (marketing, distribution, administration)
Setiyawan et al. (2021) [19]	Indonesia	Minimise total cost of the supply chain network	Operational cost, closing cost, production cost, transportation cost, production capacity, demand in market zone
Chukwuma (2015) [20]	Nigeria	Minimise supply chain cost	Shipping cost, total supply and warehouse capacity, market demand

Table 3. Gap for further research in the cement distribution network.

Objective	Recent studies	Further research
Minimise transportation cost	Yes	Yes
Maximise service level (delivery lead time)	No	Yes

3. Methodology

To solve the distribution network optimisation problem, the research is conducted in a quantitative method using linear programming. The condition can be adjusted to the desired environment by using the constraints or limits in the values of the formula. The model is similar to linear programming, which uses operations research techniques to find the optimal solution. The model includes all the constraints related to transportation cost and service level. The model's main assumption consists of many parameters in demand and supply constraints. It includes the cement demand in each province, the potential location of depots, warehouse capacity, fixed cost and variable cost, transportation weight and cost, and expected service level in each area. Apart from the parameters, the model also includes the variables to decide location selection and the number of shipments between the warehouse and end customer location. All these constraints are developed in the model with the main objective of minimising transportation costs while satisfying service level or delivery lead-time.

The investment in a new distribution centre for bagged cement is not high as the company can rent the available warehouse in a short- or medium-term contract. The company can analyse the data to group the demand into the desired cluster and find the centre of gravity to select the area as a potential location for further decisions in the distribution model. There are several steps to designing a distribution network for bagged cement in Northeast Thailand. The first step is data collection, gathering information on cement demand, warehouse fixed cost, transportation cost (vary by distance), operation cost, and expected service level (delivery lead-time). After getting all the necessary information, the next step is to develop the centre of gravity to find the potential location of depots. The third step is constructing the mathematical model to solve the facility location problem and ensure the solution satisfies all demands in each area. The final step compares the existing distribution network and the new optimisation model in terms of total cost and service dimension.

For the data collection process, the result is generated from the assumption of many parameters by researching the annual report, existing academic research, or business documents. This is important for the model to list all reasonable data that realise the current market situation. Cement demand is the initial target, and the formula is ensured to satisfy all demand in each area since the company must serve the product to their customers. In the business aspect, the data on warehouse rental, operating, and transportation costs will gather from business-related documents such as previous studies, quotations from the company, or online business platforms. Other necessary data is the assumption of transportation strategy, which consists of truck capacity, warehouse utilisation, and competitiveness in the market in terms of cost and time. When all information is available, the centre of gravity (COG) is necessary for the model to seek geographic coordinates for the suitable location of depots. This is one of the methods to analyse the area that contributes to minimising last-mile transportation costs. However, the company could only select some potential locations simultaneously as it would lead to high rental and operating costs.

The next step is to create a mathematical model using Linear Programming, which will use Microsoft Excel to find the answer in this research. The objectives are divided into two parts: finding the cheapest freight and the best level of service. The two goals are contradictory and belong to different measures of cost and time. Therefore, it is necessary to convert the measurements into the same units to find the best possible optimised answer. It can use conversion to the percentage of satisfaction with the solution. The process of defining satisfaction is designed from the range of responses to be obtained. For example, to find the cheapest cost, the answer is the least amount possible, and at the same time, the service level is the worst possible. Again, looking for the answer of the best service level means the highest cost. Therefore, from both the problems, the lowest and highest values of each answer can be obtained and converted to satisfaction by giving the lowest cost to 100% satisfaction in cost and reducing the proportion to the most expensive cost is 0% satisfaction. Regarding service level, it gives the shortest last mile distance to 100% satisfaction and scales down to the worst level to 0% satisfaction. When two objectives are in the same unit of measure, optimisation can be obtained by achieving the highest satisfaction value from both goals. Two objective functions aim to minimise cost and maximise the service. The research formulates a mathematical model to optimise the multiple criteria decision-making, which needs a compromise process to select the appropriate solution. The essential steps for an optimisation model start from organising all the data to simulate the objective function subject to certain constraints or limitations on the value. Then, the Excel solver can select the cell to define the decision variable, constraints, and objective function. The complexity of the model depends on the number of parameters and the number of locations involved in the location facility problem.

The purpose of this research is to achieve the multiobjectives which are contradictory. When the company wants to minimise transportation costs, it means having as few distribution centres as possible to save on warehouse management costs and reduce the double handling process. On the other hand, it is necessary to have distribution centres closer to the end customers' area when the company aims to improve service levels by reducing delivery lead time.

Ignizio (1983) [21] describes the general principle of linear programming as finding a solution to an objective function, often a solution that minimises or maximises the objective. The basis of linear programming is applied to multiobjective models with relatively large problem sizes and is often applied to real-world cases. The main principle is to convert the units of measurement into the same unit, known as generalised linear programming, to solve problems with conflicting objectives. In addition, Jones and Tamiz (2010) [22] described a similar principle called Percentage Normalisation to change the unit of measurement to a percentage value away from the target level. In conclusion, this research solves the problem of conflicting objectives with different units of measure (THB and KM) by converting the unit of measurement to the same unit as the percentage. Then, find the most optimised point closest to the best answer for both objectives.

3.1. Data Collection

Before creating a mathematical model for solving the facility location problem, the completed information is required. This includes the cement demand in each area, transportation distances, cost, and distribution centres data.

3.1.1. Assumptions

The main assumptions used in developing the model are listed as the followings:

- The distribution network is in a forward direction from production (factory) to the distribution centre, distribution centre to the dealer, or from factory directly deliver to the dealer.
- A fleet of 32-ton trucks (18-wheels) is used to deliver the cement bag from the origin of a factory to any location, and a fleet of 10-ton trucks (6-wheels) is used to shuttle from the distribution centres to the dealer.
- All trucks are assigned to carry at their full load capacity.

The next part of the assumption is to define the location of the factory and warehouse to calculate in the model. For example, the cement factory in Saraburi has a delivery to customers in the Northeast region of Thailand covering 20 provinces. This assumption determines each province's location that the factory or warehouse is located in the city districts of each province. Then, convert from the latitude and longitude to the transportation distance from one point to another province. Finally, the distance obtained from the calculation is plotted in the matrix. The transportation costs are calculated per ton per kilometre (PTPK), and the transportation rates vary depending on the distance and type of truck used. The freight rates are shown in Table 4.

Table 4. The transportation rate per ton per kilometre by distance by truck type.

Distance		Per ton per KM (PTPK)	
From (KM)	To (KM)	18-wheels (32 tons)	6-wheels (10 tons)
0	50	2.13	5.11
50	90	1.38	2.87
90	130	1.23	2.30
130	180	1.15	2.20
180	250	1.08	2.11
250	360	1.02	1.97
360	410	0.99	1.85
410	450	0.98	1.75
450	500	0.96	1.70
500	650	0.95	1.63
650	750	0.94	1.55
750	970	0.93	1.48
970	1,250	0.92	1.28
1,250	1,450	0.91	1.21
1,450	1,600	0.90	1.15
1,600	2,000	0.89	0.9

Apart from the transportation costs, the distribution centre costs must also be considered in the total transportation cost. In this calculation model, distribution centre capacity, fixed rental price, and management price varying with cement volume are assumed to be the same in all provinces.

Table 5. The distribution centre capacity and cost.

Item	Cost	Unit
Maximum Capacity	360,000	Tons per year
Fixed Cost	7,200,000	THB per year
Variable Cost	40	THB per Ton

The last data input needed for the mathematical formulation is the cement demand. In this research, the assumption is made from the population (National Statistical Office, 2022) [23] and Thailand's cement consumption per capita per year (Korea Cement Association, 2013) [24] to calculate cement consumption in each province. Then, apply the market share of Company A to find out how much the company must distribute products to each area (Table 6).

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Table 6. Cement demand by province per year.

Consumption per capita 366 kg/year

Province	Population	Cement consumption	Company A	
			Market share	Tons/year
Nakhon Ratchasima	2,634,154	964,100	44%	426,724
Buri Ram	1,579,805	578,209	30%	175,961
Surin	1,376,230	503,700	14%	71,211
Si Sa Ket	1,457,556	533,465	10%	52,117
Ubon Ratchathani	1,868,519	683,878	23%	158,271
Yasothon	533,394	195,222	7%	13,035
Chaiyaphum	1,122,265	410,749	1%	3,948
Amnat Charoen	376,350	137,744	7%	10,000
Bueng Kan	421,995	154,450	6%	10,000
Nong Bua Lam Phu	509,001	186,294	28%	52,068
Khon Kaen	1,790,863	655,456	30%	197,664
Udon Thani	1,566,510	573,343	14%	80,413
Loei	638,732	233,776	45%	105,077
Nong Khai	516,843	189,165	3%	5,123
Maha Sarakham	948,310	347,081	27%	95,310
Roi Et	1,296,013	474,341	3%	14,274
Kalasin	975,570	357,059	11%	38,828
Sakon Nakhon	1,146,286	419,541	8%	34,052
Nakhon Phanom	717,040	262,437	6%	16,820
Mukdahan	351,484	128,643	67%	86,235
	21,826,920	**7,988,653**	**21%**	**1,647,129**

3.2. Mathematical Formulation

Nooranda and Vanany (2021) [17] have published research on minimising supply chain costs using linear programming to develop a distribution optimisation model. However, the research focuses solely on minimising costs and the service aspect has never been shown in other existing research on cement distribution. The parameter related to delivery distance, an important factor affecting service level, needs to add to this study and requires the second objective to maximise the service level. Therefore, it is necessary to formulate a new mathematical model for the specific situation in the cement market in Thailand as explained earlier.

To solve the problem discussed in the previous section, a linear programming model is formulated with essential components: indices, decision variables, variables, objective functions, and constraints.

3.2.1. Indices

- i ϵ I Set of production (factory)
- j ϵ J Set of distribution centres
- k ϵ K Set of dealers (customer)

3.2.2. Parameters

- XY_{ij} amount of cement from factory i to distribution centre j
- YK_{jk} amount of cement from distribution centre j to dealer k
- XK_{ik} amount of cement from factory i to dealer k
- DX_{ij} distance from factory i to distribution centre j
- DK_{jk} distance from distribution centre j to dealer k
- DZ_{ik} distance from factory i to dealer k
- CX transportation cost (large truck) from factory i to distribution centre j
- CY transportation cost (small truck) from distribution centre j to dealer k
- CZ transportation cost (large truck) from factory i to dealer k
- SY_j maximum storage capacity of distribution centre j
- TS small truck capacity (ton)
- TL large truck capacity (ton)
- VY_j variable cost of distribution centres j
- BY_j investment (fixed) cost of distribution centre j
- XX_i amount of cement at i (factory)

3.2.3. Decision Variables

$$UY_j = \begin{cases} 1, \text{if distribution centres is located at location j} \\ 0, \text{otherwise} \end{cases}$$

3.2.4. Variables

- $NX_{ij} =$ the number of times per day that cement is transported from factory i to distribution centre j
- $NY_{jk} =$ the number of times per day that cement is transported from distribution centre j to dealer k
- $NZ_{ik} =$ the number of times per day that cement is transported from factory i to to dealer k

3.2.5. Objective Functions

3.2.5.1. Cost objective function

$$f^C = \left(\sum_j BY_j * UY_j\right) + \left(\sum_j VY_j * YK_{jk}\right) + \left(\sum_{ij} CX * DX_{ij}\right) + \left(\sum_{ik} CZ * DZ_{ik}\right) + \left(\sum_{jk} CY * DK_{jk}\right) \quad \text{(F.1)}$$

3.2.5.2. Service objective function

$$f^S = DZ_{ik} + DX_{ij} \quad \text{(F.2)}$$

3.2.6. Constraints

$$XY_{ij} \leq NX_{ij} * TL \quad \forall i,j \in I,J \quad \text{(C.1)}$$

$$YK_{jk} \leq NK_{jk} * TS \quad \forall j,k \in J,K \quad \text{(C.2)}$$

$$XK_{ik} \leq NZ_{ik} * TL \quad \forall i,k \in I,K \quad \text{(C.3)}$$

$$\sum_i XY_{ij} \leq SY_j * UY \quad \forall i,j \in I,J \quad \text{(C.4)}$$

$$\sum_j XY_{ij} + XK_{ik} = XX_i \quad \text{(C.5)}$$

$$\sum_k YK_{jk} + = \sum_i XY_{ij} \quad \text{(C.6)}$$

$$XY_{ij} \geq 0 \quad \forall i,j \in I,J \quad \text{(C.7)}$$

$$YK_{jk} \geq 0 \quad \forall j,k \in J,K \quad \text{(C.8)}$$

$$XK_{ik} \geq 0 \quad \forall i,k \in I,K \quad \text{(C.9)}$$

$$NX_{ij} \geq 0 \quad \forall i,j \in I,J \quad \text{(C.10)}$$

$$NX_{jk} \geq 0 \quad \forall j,k \in J,K \quad \text{(C.11)}$$

$$NZ_{ik} \geq 0 \quad \forall i,k \in I,K \quad \text{(C.12)}$$

3.3. Spreadsheet

Once the data has been gathered and the mathematical model has been written, the next step is to insert the data into a spreadsheet (Microsoft Excel) to calculate the result based on the objectives set for each scenario. In sheet 1, it is Input data or Parameters used for calculation. This includes distance, transportation costs by distance and vehicle type, cement demand, distribution centre establishment and handling costs, and the capacity of each distribution centre.

3.3.1. Input data

For distances, the model uses inter-provincial transportation distance information to be the value for calculating the distance from the factory to distribution centres and from distribution centres in each area to dealers in different provinces. In the case of distribution in the same province, an average distance of 15 kilometres is used to calculate the cost of a small truck for last-mile delivery.

Freight costs consist of 2 main parts: transporting product from the Saraburi by receiving cement bags from the factory and distributing the product from distribution centres. From the factory, the product will be transported by a large truck (18-wheels, 32 tons) and delivered to the distribution centre in each province or directly transferred to dealers, who are the final customer for the company. While the other type will be the distribution of products from regional distribution centres using small trucks (6-wheels, 10 tons) to deliver smaller orders to customers, which increases the options to order and reach a broader range of customers to increase sales opportunities. However, the cost of both types of transportation will be divided into prices per ton per kilometre according to the actual transportation distance. Due to transportation over longer distances, fixed costs such as monthly car rental or car instalment costs, insurance costs, and driver wages are averaged by the amount of distance travelled, reducing the price per kilometre. Therefore, in using the freight cost table in the calculation, the formula has been written according to the type of truck and the transportation distance to get the cost the most accurate to reality.

In terms of cement demand, using the calculation of the cement consumption per capita, the input in the spreadsheet to generate the mathematical model also uses the province's overall cement amount per year to ensure that the company can serve all cement demand.

In linear programming to find the multiobjective solution for the facility location problem, the limits of the storage capacity of each area must be set. Therefore, from the assumption of the fixed cost, variable cost, and the distribution centre capacity, the data has been used in the spreadsheet in the input part by separating by provinces that are considered in establishing a new distribution centre.

3.3.2. Add-in program in the spreadsheet

After all the necessary data for the calculation has been inserted into the spreadsheet, the next step is to prepare the calculation template and select the data according to the mathematical formulation described in the past section. Usually, linear programming can be solved by using the Excel Solver function, part of Microsoft Excel. However, the equations for solving this research problem contain many variables and constraints that might exceed the Excel Solver's limitation. Therefore, the author considers to uses an open-source program for solving linear programming problems called OpenSolver (Fig. 4), which has the same feature and working principles as the Excel Solver function but differs in that it has to be downloaded and installed in the add-on before start solving the problem. This program can solve the linear programming problem without limiting the number of variables and constraints.

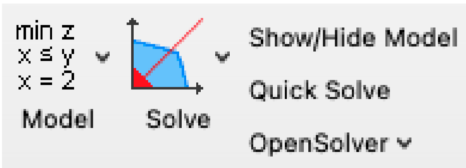

Fig. 4. The add-in program (OpenSolver) in Microsoft Excel.

3.3.3. Calculation Model

To solve the problem, the calculation model must use the data entered into the Input sheet and create the table for the results of variables, decision variables, and constraints to satisfy the conditions and assumptions set in the input. The first part of the model is variables consisting of the volume of cement bags transported from the Saraburi plant to various distribution centres, where the model results are established in each province, and another part is the product delivery to the end customer from the origin of both factories and distribution centres. The total amount of cement delivered to customers must equal the demand in each province and not exceed the maximum capacity of each distribution centre.

The next part is the decision variable that must be calculated where the new distribution centres need to be established. Again, each area will have a fixed cost as one of the deciding factors.

Another section of the model is the constraint, ensuring the answer is within a specific range. For example, the combined volume of the cement delivered from the factory and distribution centres must meet the demand, or the company can respond to all customer needs. Another part is the amount of inbound product to each distribution centre must not be negative, which cannot happen in real situations.

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After preparing the calculation space, the next step is to open OpenSolver using the 'Model' function to select all the variables and decision variables (Fig. 5). Then, fill in all the constraints as written in the mathematical formulation.

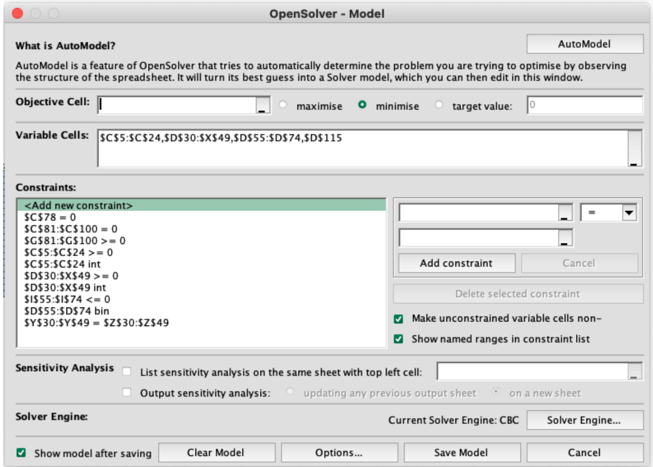

Fig. 5. The selection of variables cell and constraints in the model.

3.3.4. Minimise cost

The first scenario is to find the most minimised transportation costs. To find the best solution, the objective of the model must be set by using OpenSolver to select the Minimise Objective. The objective cell is the total transportation cost calculated from the freight from the factory to the distribution centre, factory to the dealer, distribution centre to the dealer, and fixed and variable costs of the distribution centre.

3.3.5. Maximise service level

The second scenario is to find the answer that results in the best service level. With the same method as the previous objective, it can be done by setting the model's objective to the shortest last mile delivery distance or minimising the objective to deliver to the customer as quickly as possible and make the result to the best level of service. Therefore, the objective cell is the formula to combine all last-mile delivery distances from direct factory-to-customer distribution and distribution centres to customers in each province.

3.3.6. Optimise cost and service level

To find the optimum answer for two conflicting objectives, the units of measure for the two objectives must be converted to the same unit, which in this research will change to the form of a percentage. The answer in scenario 1 is the minimum cost result, while the service level result is the maximum that can be happened. On the other hand, the result obtained from scenario 2 is the minimum value of the service level and the maximum value of the transportation cost. These figures are used as the upper and lower bound of the score and calculated as objectives' satisfaction scores. The constraint of this model has set the satisfaction score of each objective within the upper and lower range of the previous two scenarios. At the same time, the overall satisfaction score is less than or equal to the lowest score across the two objectives. The objective for scenario 3 is to find the result that gives the highest satisfaction score for both objectives. Therefore, the setting in the model is to maximise the satisfaction score equivalent to the satisfaction score from the conflicted objectives.

3.3.7. Solve the optimisation model

After all the inputs have been entered into the spreadsheet and the variables, constraints, and objective functions have been set in the model. The next step is using the OpenSolver tool to run the optimisation model to find the answer separately for all three scenarios. Suppose the program can find a solution that satisfies all constraints. In that case, it displays a screen indicating that the optimisation model has been successfully run and that the optimal solution was obtained using linear programming (Fig. 6). Finally, the answer will be displayed on the spreadsheet in the variables and objectives section.

Fig. 6. The outcome from the optimisation running.

4. Results

The result consists of two main parts: 1) the centre of gravity and 2) the results obtained from the mathematical model to solve the facility location problem by attempting to optimise transportation costs and service levels.

4.1. Centre of Gravity

Ying (2014) [25] researched the location of a suitable logistics distribution centre using the centre of gravity method and described the principle of this method as one of the logistics network planning solutions. The calculation to find the centre of gravity consists of two main components: 1) the weight or demand of goods in a given area and 2) the geographic coordinates or latitude and longitude of those areas. Therefore, a method of finding the centre of gravity is suitable for the single potential location, which indicates an ideal location for a centralised distribution centre.

The first part of the results in the centre of gravity is the demand for cement. The calculation is based on the assumption of cement per capita in Thailand and the population in the Northeast region to determine the amount of cement used in each area. Then find the number of products that the company has to deliver to each province by using the market share and cement consumption. The results show that the demand for cement is approximately 1.65 million tons per year, or about 137,000 tons per month (Table 7).

Table 7. Bagged cement consumption in Northeast Thailand.

Province	Population	Cement consumption	Company A	
			Market share	Tons/year
Nakhon Ratchasima	2,634,154	964,100	44%	426,724
Buri Ram	1,579,805	578,209	30%	175,961
Surin	1,376,230	503,700	14%	71,211
Si Sa Ket	1,457,556	533,465	10%	52,117
Ubon Ratchathani	1,868,519	683,878	23%	158,271
Yasothon	533,394	195,222	7%	13,035
Chaiyaphum	1,122,265	410,749	1%	3,948
Amnat Charoen	376,350	137,744	7%	10,000
Bueng Kan	421,995	154,450	6%	10,000
Nong Bua Lam Phu	509,001	186,294	28%	52,068
Khon Kaen	1,790,863	655,456	30%	197,664
Udon Thani	1,566,510	573,343	14%	80,413
Loei	638,732	233,776	45%	105,077
Nong Khai	516,843	189,165	3%	5,123
Maha Sarakham	948,310	347,081	27%	95,310
Roi Et	1,296,013	474,341	3%	14,274
Kalasin	975,570	357,059	11%	38,828
Sakon Nakhon	1,146,286	419,541	8%	34,052
Nakhon Phanom	717,040	262,437	6%	16,820
Mukdahan	351,484	128,643	67%	86,235
	21,826,920	**7,988,653**	**21%**	**1,647,129**

When the amount of cement demand in each area is known, it can be used to find the centre of gravity. The way to calculate the result is to add all the results of geographic coordinates multiplied by the object's weight or the demand for the product in this research. Then divide by the total cement volume to find the centre of latitude and longitude.

Table 8. Centre of gravity for a potential distribution centre in Northeast Thailand.

Province	Long (X)	Lat (Y)	Long*Q	Lat*Q	Distance (KM)	Cement Demand (Tons/year)
Nakhon Ratchasima	102.103	14.981	43,569,801	6,392,752	126	426,724
Buri Ram	103.064	14.960	18,135,245	2,632,377	281	175,961
Surin	103.515	14.896	7,371,407	1,060,759	328	71,211
Si Sa Ket	104.349	15.077	5,438,357	785,768	442	52,117
Ubon Ratchathani	104.845	15.299	16,593,923	2,421,388	500	158,271
Yasothon	104.175	15.844	1,357,921	206,527	402	13,035
Chaiyaphum	102.053	15.835	402,905	62,517	202	3,948
Amnat Charoen	104.631	15.874	1,046,310	158,740	456	10,000
Bueng Kan	103.581	18.318	1,035,810	183,180	621	10,000
Nong Bua Lam Phu	102.395	17.168	5,331,503	893,903	402	52,068
Khon Kaen	102.818	16.453	20,323,417	3,252,166	318	197,664
Udon Thani	102.778	17.402	8,264,687	1,399,347	437	80,413
Loei	101.713	17.535	10,687,697	1,842,525	435	105,077
Nong Khai	102.776	17.849	526,521	91,440	497	5,123
Maha Sarakham	103.327	16.120	9,848,096	1,536,397	342	95,310
Roi Et	103.614	16.011	1,478,986	228,541	365	14,274
Kalasin	103.551	16.511	4,020,678	641,089	388	38,828
Sakon Nakhon	104.145	17.167	3,546,346	584,571	517	34,052
Nakhon Phanom	104.696	17.322	1,760,987	291,356	607	16,820
Mukdahan	104.619	16.561	9,021,819	1,428,138	523	86,235
	103.066	**15.842**	**169,762,416**	**26,093,481**		**1,647,131**

From Table 8, the centre of gravity of the potential location of the distribution centre is at latitude 15.842 and longitude 103.066. The result corresponds to the centre of gravity calculation principle using the object's weight. It can be observed that when multiplying the demand with the geographical coordinates, the weight will pull the coordinate axis toward that location. For example, the Long*Q and Lat*Q of Nakhon Ratchasima have the highest total number, making the centre of gravity most likely to be located near that area.

The result of the calculated centre of gravity obtained as a latitude and longitude can determine its place in the real-world map. When plotting the geographic coordinates on the map, the place is located in Maha Sarakham, one of the provinces in the middle of the northeastern region. However, the exact location is somewhat to the lower left toward Nakhon Ratchasima and Khon Kaen, two provinces with the highest cement demand in the area. Figure 7 shows the position obtained as the centre of gravity, where the colour intensity varies according to the cement demand in each province. The light colours represent the area with the small volume and the intensity increases to the dark tone for higher demand. The centre of gravity is pinned down close to a high-demand location surrounded by areas of medium to very dark shades.

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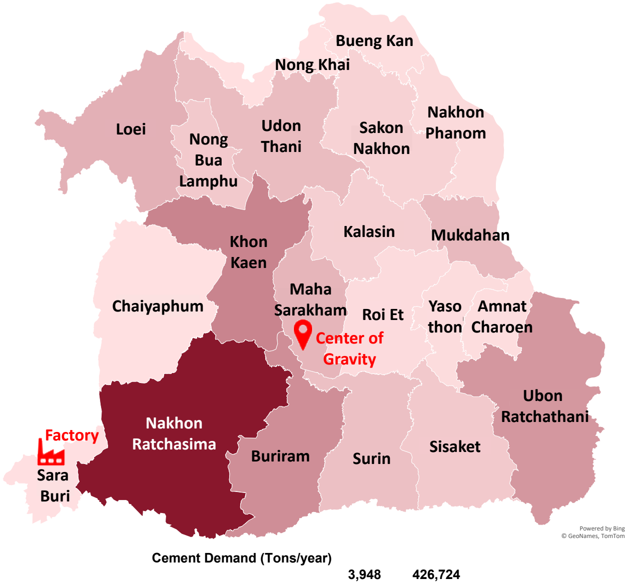

Fig. 7. Cement demand and the centre of gravity in Northeast Thailand.

4.2. Mathematical Model for Facility Location Problem

The remaining part of the results is a mathematical model section in which this research aims to optimise transportation costs and service levels (delivery lead time). There are a total of 3 sets of scenarios:

Scenario 1: Minimise cost
Scenario 2: Maximise service level
Scenario 3: Optimise cost and service level

4.2.1. Minimise cost

For the first model, it was calculated to solve the facility location problem by setting an objective function to obtain the lowest distribution cost. The result of this scenario is the possible lowest cost and the possible longest last-mile delivery distance. The results (Fig. 8) show that all products should be shipped from a single location, the plant located in Saraburi, and directly shipped to the end customer to reduce the cost of setting up a distribution centre and warehouse management cost.

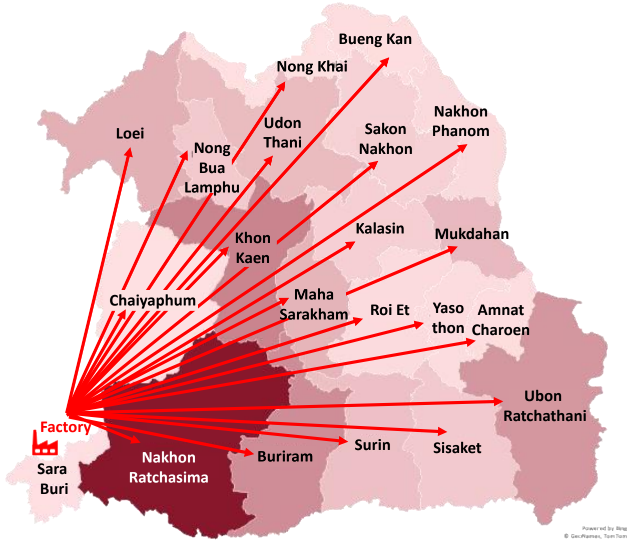

Fig. 8. The distribution flow for Scenario 1.

Table 9 shows the results from Scenario 1 which the total transportation cost is 564 million baht per year, occurring from only the cost of delivery to the end customer. At the same time, the total last-mile distance is 562 million kilometres per year.

Table 9. The summary of results from Scenario 1 (Minimise cost).

Total Cost (MTHB per year)	564
Inbound transportation cost	-
Distribution center fixed cost	-
Distribution center operating cost	-
Outbound transportation cost	564
Last Mile Distance (KM per year)	562,070,603

The results from Scenario 1 include the total last-mile distance per year, the average last-mile distance per trip, the delivery lead time for each province, the transportation cost per trip, and the annual transportation cost. In summary, the results are consistent with the current situation of the company, with an average transportation cost of 342 THB/ton with an average delivery lead time of 1.35 days.

4.2.2. Maximise service level

In Scenario 2, an objective function is set to determine the distribution of bagged cement at the best service level. The service level is a direct variation of the last-mile delivery distance since the delivery lead time will be faster when the distance from the distribution point to the end customer location is reduced. The results are easy to predict as the minimum last-mile distance must be delivered from a distribution centre in the same province. Therefore, to achieve the maximum service level, all provinces should have distribution centres in their area, as shown in Fig. 9.

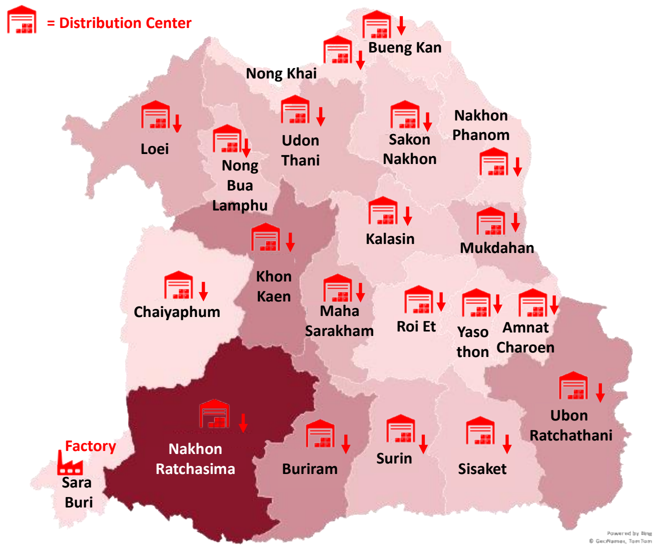

Fig. 9. The distribution flow for Scenario 2.

The results from Scenario 2 (Table 10) are represented by a parameter that results in the best service level, which is the possible shortest last-mile distance at 32 million kilometres per year. On the other hand, the cost of transportation incurred by this model is the highest cost that can be incurred, equivalent to 913 million baht per year. The costs mentioned above arise from the transportation of bagged cement from the plant in Saraburi to distribution centres in various provinces, known as inbound transportation costs, at 568 million baht per year. The cost of distribution centres is 210 million baht per year, consisting of fixed costs of 144 million baht per year and operating expenses that vary to the product volume, costing around 66 million baht annually. The outbound transportation cost to deliver the product from distribution centres to end customers is approximately 135 million baht per year.

Table 10. The summary of results from Scenario 2.

Total Cost (MTHB per year)	**913**
Inbound transportation cost	568
Distribution center fixed cost	144
Distribution center operating cost	66
Outbound transportation cost	135
Last Mile Distance (KM per year)	**31,712,985**

The details of the results obtained from Scenario 2 contain the same dataset as in Scenario 1. The key finding is the average transportation cost of 555 baht per ton with an average delivery lead time of 1 day.

4.2.3. Optimise cost and service level

Scenario 3 has an objective function to calculate the optimisation point of transportation cost and service level. The results were calculated from the satisfaction level of the outcomes in Scenarios 1 and 2, which are set as the upper and lower boundaries of the possible results. If the outcome is the lowest transportation cost incurred as a result of Scenario 1, then the satisfaction level in the cost dimension is 100%. Conversely, the maximum transportation cost incurred by Scenario 2 accounted for a 0% satisfaction level and increased proportionally between the upper and lower bounds of the result. This principle also applies to the service level dimension, where the highest service level achieved in Scenario 2 is 100% satisfaction and 0% if the result reached the lowest service level, according to the result from Scenario 1.

This study calculated satisfaction scores by assigning weights to the two objectives, transportation cost and service level (last-mile distance). Then, the graph is plotted in the form of sensitivity analysis to show the variation when applying the different weights in objectives. Fig. 10 shows that when the cost objectives are not focused, the result of distance is the most minor meaning the best level of service. In contrast, the transportation cost is incurred at the highest level compared to giving more weight to cost objectives in the mathematical model.

When calculating by assigning more weight to the cost objective, the service levels worsen, as seen from the last-mile increase. Therefore, to balance transportation cost and service level, the two main objectives which are equally crucial to the customer's decision to purchase bagged cement, this research selected equal weight on two goals, 50% on cost and 50% on service level, in the mathematical model to calculate Scenario 3. The result obtained by this method is the best possible result of the conflicting objectives, which is considered an optimised result.

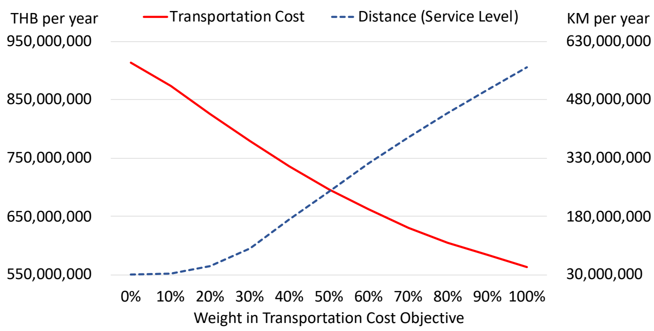

Fig. 10. The sensitivity analysis of different weights in main objectives.

The results from the Scenario 3 suggest that the products should distribute from a total of 6 origins. The supply location consists of the Saraburi plant, which distributes to the destination in 10 provinces, and from 5 distribution centres to the end customer in 10 areas (Fig. 11).

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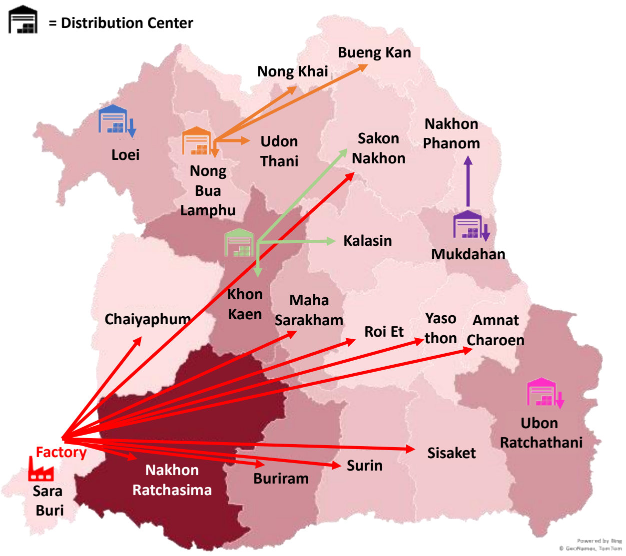

Fig. 11. The distribution flow for Scenario 3.

The optimum result between the lowest freight cost and the best level of service renders approximately 60% of the lowest and highest value from the previous two scenarios. As a result, the total transportation cost is 696 million baht annually. It consists of the cost of transporting the product to distribution centres of 322 million baht, the cost of the distribution centre of 67 million baht per year (fixed 36 million baht and the variable 31 million baht), and last-mile transportation costs to destinations of 307 million baht per year. In comparison, the total last-mile distance is 245 million kilometres per year (Table 11).

Table 11. The summary of results from Scenario 3.

Total Cost (MTHB per year)	**696**
Inbound transportation cost	322
Distribution center fixed cost	36
Distribution center operating cost	31
Outbound transportation cost	307
Last Mile Distance (KM per year)	**244,697,042**

In terms of details, the key information obtained from the mathematical model is the average transportation cost of 422 baht per ton and the average delivery lead time of 1.05 days. The overall satisfaction scores for the optimisation outcomes between the cost and service level in Scenario 3 are approximately 60% (Table 12). Satisfaction with transportation costs is at the same level at 62%, and satisfaction with service level is at 60%.

Table 12. Overall satisfaction scores.

	Satisfaction	**Optimum**	**Maximum**	**Minimum**
Transporation Cost (Million THB/year)	62.31%	696	913	564
Service level (Million KM/year)	59.84%	245	562	32
Multi-objectives	**59.84%**			

4.3. Key Findings and Analysis

Considering the first result obtained from the study, the location is located in the middle when calculating the demand for cement in each area, which is Maha Sarakham Province. Suppose the company wants to distribute products from that location to all areas with a higher level of service than its competitors. It might be challenging to implement this practice since the overall demand for cement will reach 480K tons per year, which impacts the space to set up the distribution centre must be huge, and the operation is more complex. Also, the number of people or machines used in that distribution centre will be considerable and require high investment, becoming a long-term strategy that reduces the flexibility of the company in operating the business.

From the results obtained from the mathematical model, the data suggests three different responses based on the objective function set in each model. In scenario 1, the expected answer should be the same as the strategy in which cement Company A is currently operating its business, intending to manage the distribution with the lowest transportation costs. The reason why Scenario 1 is the same as the company is that all the cement bags are delivered from a single factory in Saraburi. Due to the delivery from production, there are no distribution centre management costs, including rental and double handling costs. Therefore, the answers obtained from scenarios 2 and 3 are expected to have higher total transportation costs than scenario 1.

The transportation cost obtained from the optimisation model (scenario 3) results in 696 million baht per year. It is increased from scenario 1, which has the lowest cost at 23%, while cheaper than scenario 2, with the most expensive transportation cost at 24%. However, the service level in this research uses the last mile delivery distance as an indicator is 56% better than the cost-minimisation objective model, as shown in Table 13.

Table 13. The comparison between multiobjective (Scenario 3) and cost objective (Scenario 1).

	Cost Minimisation Objective	**Multi-Objective (Optimization)**	**Different**	
Transportation Cost (MTHB per year)	564	696	+132	+23%
Last Mile Distance (Million KM per year)	562.1	244.7	-317.4	-56%

When comparing the results obtained from all three scenarios, the value of the optimisation model is in the range between scenario 1 with the lowest cost and the second scenario 2 with the highest service level (the minimum last-mile delivery distance). The optimisation result is approximately 60-62% satisfaction in terms of costs and service levels.

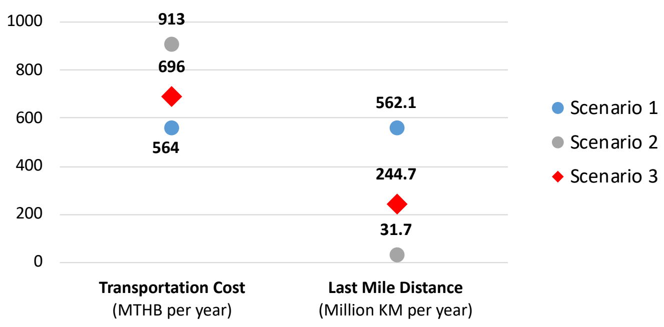

Fig. 12. The comparison of cost and distance between 3 scenarios.

Apart from comparing the results obtained from the calculation of all three scenarios, the total transportation cost is increased if the optimisation model (Scenario 3) is compared with the current situation (Scenario 1) or the operating model that the company chooses to run its business. The total transportation cost of the current strategy is originally averaged at 342 THB per ton when shipping to dealers in the Northeast, but the result from the optimisation model is increased to 422 THB per ton on average when making a strategy adjustment by considering opening a distribution centre in some provinces instead of delivering from a single factory. It represents a 23% price increase or 80 THB per ton increase higher than the current cost. A significant part of the increase in transportation costs is the result of the recommendation to open five distribution centres to deliver products to 11 provinces. In contrast, the rest of the nine provinces that still supply from factories still have the same delivery cost.

However, the model recommends opening more distribution centres. This is due to efforts to reduce overall delivery lead time to increase competitiveness with other competitors who can have a faster delivery lead time to serve to product to the market. This makes customers who need products consider changing the brand of the product to be able to respond to the demand immediately. As a result, the optimisation model reduced the average delivery lead time by 0.44 days or a 33% improvement over the current delivery strategy (Table 14). The key improvement is the significant reduction in delivery times across seven provinces from 2 days to 1 day, which is to leverage to be the same as other competitors in the same industry. This can be considered to increase the opportunity to compete with competitors in terms of logistics and allows the company to focus on other aspects of the business, such as price or marketing, that will enable the company to compete with other companies in the bag cement market in the Northeast of Thailand.

Table 14. The comparison between the current operating model and the optimisation model.

Province	Est. Volume (Tons/year)	Distance (KM)	Est. Transportation Cost (THB/ton)			Delivery Lead Time (Day)		
			Current (Min Cost)	Optimisation Model	Diff	Current (Min Cost)	Optimisation Model	Diff
Amnat Charoen	10,000	456	466	466	0	2	2	0
Bueng Kan	10,000	621	608	787	179	2	1	-1
Buri Ram	175,961	281	284	284	0	1	1	0
Chaiyaphum	3,948	202	242	242	0	1	1	0
Kalasin	38,828	388	404	613	209	1	1	0
Khon Kaen	197,664	318	350	514	164	1	0.5	-0.5
Loei	105,077	435	414	578	164	1	0.5	-0.5
Maha Sarakham	95,310	342	360	360	0	1	1	0
Mukdahan	86,235	523	531	694	164	2	1	-1
Nakhon Phanom	16,820	607	599	823	223	2	1	-1
Nakhon Ratchasima	426,724	126	173	173	0	1	1	0
Nong Bua Lam Phu	52,068	402	413	577	164	1	0.5	-0.5
Nong Khai	5,123	497	498	705	207	2	1	-1
Roi Et	14,274	365	377	377	0	2	2	0
Sakon Nakhon	34,052	517	514	610	95	2	1	-1
Si Sa Ket	52,117	442	421	421	0	2	2	0
Surin	71,211	328	331	331	0	1	1	0
Ubon Ratchathani	158,271	500	477	641	164	2	1	-1
Udon Thani	80,413	437	452	647	195	2	1	-1
Yasothon	13,035	402	415	415	0	2	2	0
Total	1,647,131	327	342	422	**80**	1.35	0.91	**-0.44**

Although the results of optimisation models are promising in terms of service levels or delivery times compared to competitors in the same industry in the same area, it is shown that the company may incur higher shipping management costs than its competitors. In contrast, the level of service in some areas is better, with a faster delivery lead time as a result shown in Table 15. In the summary table, it can be seen that the company's average time is slightly lower than its competitors. In some provinces, the distribution centre is set up in the Muang District area, which has a lot of demand. For example, in Khon Kaen, Loei, and Nong Bua Lamphu provinces, deliveries can be made in 0.5 days or less due to their distribution centres located in the centre of the area.

Table 15. The comparison between the optimisation model of the company (Company A) with its competitors.

Province	Est. Volume (Tons/year)	Est. Transportation Cost (THB/ton)			Delivery Lead Time (Day)		
		A	B	C	A	B	C
Amnat Charoen	10,000	466	621	669	2	1	1
Bueng Kan	10,000	787	787	796	1	1	1
Buri Ram	175,961	284	284	284	1	1	1
Chaiyaphum	3,948	242	204	204	1	1	1
Kalasin	38,828	613	392	392	1	1	1
Khon Kaen	197,664	514	481	420	0.5	1	1
Loei	105,077	578	439	439	0.5	1	1
Maha Sarakham	95,310	360	345	345	1	1	1
Mukdahan	86,235	694	688	688	1	1	1
Nakhon Phanom	16,820	823	773	782	1	1	1
Nakhon Ratchasima	426,724	173	127	127	1	1	1
Nong Bua Lam Phu	52,068	577	406	406	0.5	1	1
Nong Khai	5,123	705	657	671	1	1	1
Roi Et	14,274	377	529	529	2	1	1
Sakon Nakhon	34,052	610	682	691	1	1	1
Si Sa Ket	52,117	421	606	606	2	1	1
Surin	71,211	331	491	331	1	1	1
Ubon Ratchathani	158,271	641	665	465	1	1	1
Udon Thani	80,413	647	597	450	1	1	1
Yasothon	13,035	415	566	566	2	1	1
Total	**1,647,129**	422	403	363	0.91	1	1

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While the average service level has improved, the delivery lead time in some provinces is still slower than in other companies. Considering the results mentioned earlier, the model calculation intends that the level of service in those provinces is slightly lower than the average because the demand for bag cement in each area is relatively small to moderate. Therefore, if there is an investment in establishing a distribution centre in those areas, it will lead to unnecessarily higher shipping costs in exchange for slightly better service. However, faster service levels in some provinces, or in other words, delivery lead time, are reduced to the same level as competitors. It has been noticed that local freight prices are slightly higher as a result of an optimisation model recommending delivering bagged cement to local dealers from newly opened distribution centres in that or nearby provinces.

In addition, provinces with distribution centres located in those areas allow the company to deliver products much faster than before. There is some area where the results of service levels look the same. In other words, the result of delivery lead time from the optimisation model is still one day equal to what is currently operating by the company. But in reality, in these three provinces, Khon Kaen, Loei, and Nong Bua Lam Phu, service levels have improved with delivery times reduced to half a day or less as distances are reduced to only about 15 kilometres on average. Nonetheless, the characteristic of bag cement dealers in the Northeast region is not an urgent need to get the product within a few hours of placing the order into the system. Therefore, delivery lead times that are too short can mean over-responding to customer demand and incur costs that do not benefit supply chain operations and the company's business. Therefore, the research considers adjusting the results obtained from the optimisation model so that it can be applied in the actual situation of the company's cement business more appropriately and efficiently. Furthermore, it focuses on making changes that reduce costs and provides the same service levels comparable to market competitors.

Table 16. The comparison between the adjusted result, the current, and the optimisation model.

Province	Est. Volume (Tons/year)	Distance (KM)	Est. Transportation Cost (THB/ton)			Delivery Lead Time (Day)		
			Current (Min Cost)	Optimisation Model	Adjusted Result	Current (Min Cost)	Optimisation Model	Adjusted Result
Amnat Charoen	10,000	456	466	466	466	2	2	2
Bueng Kan	10,000	621	608	787	787	2	1	1
Buri Ram	175,961	281	284	284	284	1	1	1
Chaiyaphum	3,948	202	242	242	242	1	1	1
Kalasin	38,828	388	404	613	613	1	1	1
Khon Kaen	197,664	318	350	514	350	1	0.5	1
Loei	105,077	435	414	578	414	1	0.5	1
Maha Sarakham	95,310	342	360	360	360	1	1	1
Mukdahan	86,235	523	531	694	694	2	1	1
Nakhon Phanom	16,820	607	599	823	823	2	1	1
Nakhon Ratchasima	426,724	126	173	173	173	1	1	1
Nong Bua Lam Phu	52,068	402	413	577	413	1	0.5	1
Nong Khai	5,123	497	498	705	705	2	1	1
Roi Et	14,274	365	377	377	377	2	2	2
Sakon Nakhon	34,052	517	514	610	610	2	1	1
Si Sa Ket	52,117	442	421	421	421	2	2	2
Surin	71,211	328	331	331	331	1	1	1
Ubon Ratchathani	158,271	500	477	641	641	2	1	1
Udon Thani	80,413	437	452	647	647	2	1	1
Yasothon	13,035	402	415	415	415	2	2	2
Total	1,647,131	327	342	422	387	1.35	0.91	1.05

The delivery lead time, as shown in Table 16, was adjusted for three provinces that take less than half a day to have the same service levels comparable to competitors. The average delivery time was slightly increased as a result of the optimisation model. The service level or average delivery time changed from the previous model by 0.14 days or 15%, but it still improved from the current strategy by 22% or a decrease of an average of 0.3 days. In another aspect, the overall freight price of the adjusted results increased from the results obtained from the optimisation model by 8% or 35 THB per ton cheaper. In comparison, it is slightly higher than the current cost by 13% or an average of 45 THB per ton.

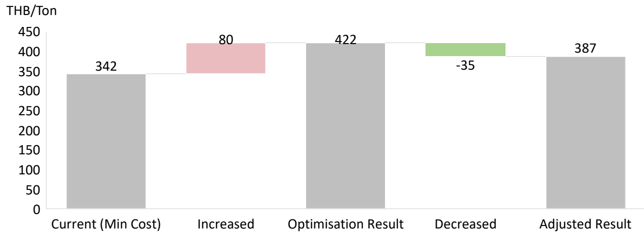

Fig. 13. The change of results (cost) from the current to the optimisation and the adjusted result.

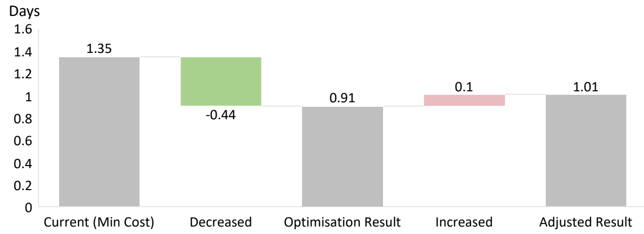

Fig. 14. The change of results (service level) from the current to the optimisation and the adjusted result.

When comparing the changes from the two outcomes in terms of freight prices and service levels or delivery times, the data in Figs. 13 and 14 show that the result in terms of transportation cost from the optimisation model is higher than the current strategy. It conflicts with improved service levels due to introducing distribution centres in multiple locations to respond quickly to the demand. However, after comparing the results with the competitors, it is found that the simulated prices after having distribution centres in many areas are considerably higher than the market prices. This may affect product pricing and make it difficult to compete. Therefore, some strategic adjustments are necessary to apply the results in real-life situations.

Considering the delivery lead time from the optimisation model, the level of service can be reduced in 3 provinces with distribution centres in Khon Kaen, Loei, and Nong Bua Lam Phu, where the delivery time was one day, equal to competitors. Therefore, establishing a distribution centre in such areas is not the main objective of increasing the service level in the area. But it is increasing the service level in nearby provinces that will supply products from the distribution centre instead of being delivered directly from the factory. At the same time, the three provinces can deliver products directly from the factory at the same lead time and cost to reduce double handling and distribution centre management costs. In addition, having distribution centres (DCs) in multiple locations also reduces the risk of shipping in the event of travel restrictions. Dealers in different areas can still place orders with safety stock reserved in each DC as well as increase the opportunity to sell in the future in case customer behaviour changes. The sales and marketing team can consider a trade-off to increasing transportation costs in exchange for better service levels quickly within a shorter time than a new DC establishment.

As a consequence, the adjusted results still recommend opening a total of 4 distribution centres for Company A's bag cement in the Northeastern region to distribute its products to 8 provinces and continue to deliver its products from the factory to the remaining 12 provinces as before (see Fig. 15). As a result, the overall transportation cost is increasing by 13% to achieve a 22% improvement in service levels.

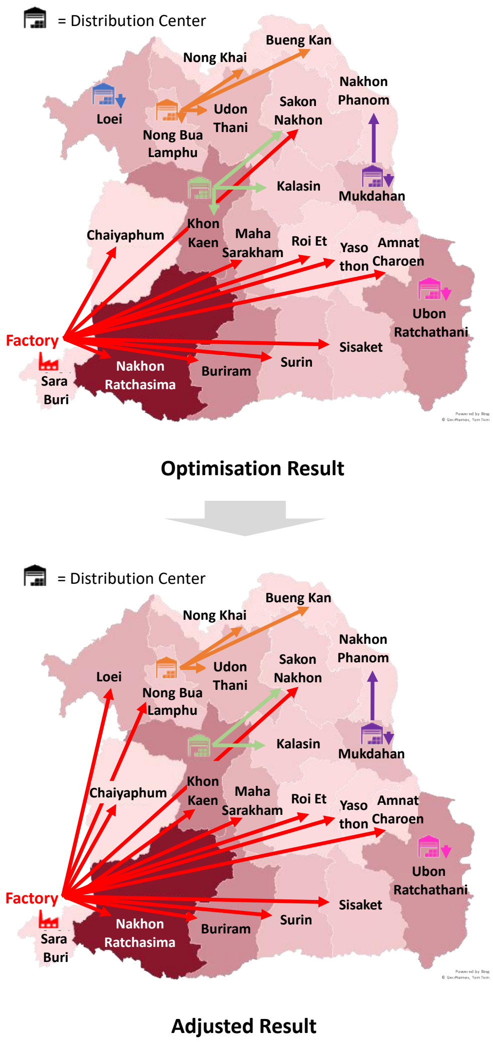

Fig. 15. The distribution flow of the optimisation model and the adjusted result.

After improving the delivery strategy, the results show that overall freight costs are in between the major competitors in the area. The average cost is 4% lower than the first company and about 7% more expensive than another. While the data in Table 17 shows that the company has a delivery lead time similar to its competitors. However, four provinces still have a longer delivery time of 2 days compared to its competitors, taking one day. The demand in those four provinces is small compared to the overall market, accounting for only 5% of the total demand for bagged cement in the northeastern region. Therefore, if the company aims to improve the service, focusing on high-purchasing dealers to maintain their market share should be the priority. Operating with a new strategy adjusted from an optimisation result will have little impact on their competitiveness. On the other hand, the company can keep the delivery cost low to create the opportunity to use the remaining money to do marketing campaigns with local customers to gain brand awareness, including promotions on various occasions.

Table 17. The comparison of the revised strategy of Company A with competitors.

Province	Est. Volume (Tons/year)	Est. Transportation Cost (THB/ton)			Delivery Lead Time (Day)		
		A	B	C	A	B	C
Amnat Charoen	10,000	466	621	669	2	1	1
Bueng Kan	10,000	787	787	796	1	1	1
Buri Ram	175,961	284	284	284	1	1	1
Chaiyaphum	3,948	242	204	204	1	1	1
Kalasin	38,828	613	392	392	1	1	1
Khon Kaen	197,664	350	481	420	1	1	1
Loei	105,077	414	439	439	1	1	1
Maha Sarakham	95,310	360	345	345	1	1	1
Mukdahan	86,235	694	688	688	1	1	1
Nakhon Phanom	16,820	823	773	782	1	1	1
Nakhon Ratchasima	426,724	173	127	127	1	1	1
Nong Bua Lam Phu	52,068	413	406	406	1	1	1
Nong Khai	5,123	705	657	671	1	1	1
Roi Et	14,274	377	529	529	2	1	1
Sakon Nakhon	34,052	610	682	691	1	1	1
Si Sa Ket	52,117	421	606	606	2	1	1
Surin	71,211	331	491	331	1	1	1
Ubon Ratchathani	158,271	641	665	465	1	1	1
Udon Thani	80,413	647	597	450	1	1	1
Yasothon	13,035	415	566	566	2	1	1
Total	**1,647,129**	387	403	363	1.05	1.00	1.00

Although the optimised result shows a significant improvement in service levels over current operations with the equivalent to competitors from the same industry in the area, a detailed analysis of the results reveals that service levels are well above the average companies currently serving their customers. When deep diving into transportation costs in those areas, the analysis identified that the cost is higher than the current operation. Even the current delivery lead time in those areas is already competitive with the same service level as other companies. The reason behind the model suggestion is that nearby provinces next to those areas take quite a long time to deliver the product to customers. Hence, distribution centres should be established in areas that are identified as the centre of gravity of that province. Besides, when the distribution centre is opened with a fixed cost which is unchanged even if the volume is high or low, the recommendation from the optimisation model is to deliver within provinces of the distribution centre's origin to shorten delivery lead time to improve service level. In addition to the required fixed costs, the delivery from the new distribution centre also has a variable cost that is considered double handling costs since the product is brought into the DC and handled before being distributed. This includes the cost of inbound transportation, distribution centre management, and outbound transportation.

To apply the results to the real business case, the related parties within the company should have a consensus meeting to align on the approach and decide on the new strategy. After simulating with an optimisation model through the linear programming method or converting the measurement of conflicting objectives into the same unit as percentage satisfaction, stakeholders should discuss the potential pros and cons and alternative approaches by using the simulation results as a guideline for a strategic supply chain. This is to continue the business smoothly with a minimal impact on the company's cost management while enhancing its competitiveness in the market through improved levels of customer service.

When comparing this study with other existing research in Section 2, the results obtained from this work can close the gap in research related to the facility location problem, which currently covers only three countries and excludes Thailand, which is the main scope of this research. In addition, other currently available studies mostly focus on cost solutions to minimise supply chain costs or maximise profitability. Thus, the dimension of improving service level is new, and this research aims to close the current research gaps to optimise the computational and simulation results of cost and delivery lead time. This is the most efficient way to change the supply chain strategy and operation regarding price and delivery time, which is beneficial for companies to apply with the real business case.

The differentiation from this research with the new aspect of the supply chain objective can improve the strategic and operational dimension in the different environments, market competition, and operating model of the cement business by delivering products in the form of Thailand's cement bags where the character is different from other countries, especially countries outside the southeast region. In terms of applying the results obtained from this research, apart from implementing strategies that have been adapted to meet the demand for cement in the specific region, the cement company can also apply a linear programming methodology that has conflicting objectives to set other purposes that the company wants to achieve and find suitable distribution centre locations in the future.

4.4. Recommendation

To apply this work to real situations, in general, individuals or companies must understand the nature of business operations, especially the demand and distribution method of bagged cement products in Thailand. Implementing a supply chain strategy from selecting a distribution centre location requires the adjustment of relevant optimisation parameters and analysing the results to better understand it before applying it to other companies cases. As mentioned earlier on the limitations of this work, future researchers who are interested in the field of bag cement distribution in Thailand may choose more unbiased or universal hypotheses. It includes the summarised results as an overall picture so that the researcher can adapt the study to other situations without changing the calculation methods or objectives. For example, the study on the location of a distribution centre is based on the population or the centre of gravity of the demand. The researcher may consider cost and service level as small factors with little impact on the result. Stakeholders can decide from the nature of the market without the necessity to simulate the result by using the optimisation model. Another purpose of future research might be to set expectations for practitioners to be able to decide quickly by designing models that are easy to use or simplify the model. The researcher may further study the relevance of various factors influencing consumers to choose a product, such as price, time to market, after-sales service, and service quality. Thereafter, researchers might select new objectives that meet the market needs of the region or that specific time to optimise the results for practical implementation. After conducting the study and presenting this research to the company, the results obtained from the suggestion of the opening of distribution centres in 4 locations were put into practice. Starting from the pilot run in the first phase by opening distribution centres in 2 locations to study the actual results to be compared with the study before deciding to take further action.

5. Conclusion

This study investigates the particular characteristics of the cement industry and the distribution of products packed in 50 kg bags to comprehend the obstacles that occur in the limited demand competition for market share acquisition. Assumptions, factors, and objectives are organised and chosen as needed for analysis and planning. However, the business constraints made this research more complex and difficult because it requires evaluating two competing objectives simultaneously. The fundamental calculating principle in this study is to modify the unit of measurement for both targets, which are the Thai baht and the last-mile delivery distance in kilometres travelled. The process entails transforming the two measurements into satisfaction scores by establishing upper and lower bounds to the highest and lowest possible values. The difference between the two numbers can be used to calculate the satisfaction percentage and set the mathematical model's objective for maximising satisfaction ratings. This research's findings contain an analysis and important findings to guarantee that the solution meets the needs of the business. Furthermore, the mathematical model results provide an in-depth answer that allows estimating the best feasible values from the two conflict objectives. However, altering the model's outcomes is required to assist the organisation in increasing flexibility and efficiency while avoiding unnecessary operations. The proposed methodology results allow the company to improve service levels by reducing the delivery lead time by 22%, bringing it to the same level as competitors with a variance of 5%. The overall freight cost increased by 13%, which is considered acceptable value from a setting target to increase cost not exceeding 15%. Thereby, the company can manage overall costs in the normal range and maintain its competitiveness in the market. As a result, the organisation has benefited by avoiding market share loss in two critical areas. The corporation chose to alter its supply chain strategy by creating distribution facilities in two of the four indicated locations based on the mathematical model's updated results. To summarise, the linear programming method can provide solid recommendations for facility location placement that can be tailored to the specific business case to increase the efficiency of supply chain strategies. In the near future, the company intends to manage the warehouse and inventory of the distribution centre to improve operational performance ([32]-[35]), which will be the subject of more study.

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