

Modeling to Reduce Transportation Costs by Linear Programming: A Case Study of the InnoFarm Biotech Company Limited

Supawat Phongwatcharawat^{1*}, Kunakorn Wiwattanakornwong² and Varis Limlawan³

¹ Lecturer, Faculty of Business Administration and Liberal Arts Rajamangala University of Technology Lanna

² Lecturer of Logistics and Supply Chain Management, College of Innovative Business and Accountancy (CIBA), Dhurakij Pundit University

³ Lecturer of Logistics and Supply Chain Management, College of Innovative Business and Accountancy (CIBA), Dhurakij Pundit University

* E-mail: Supawat@rmutl.ac.th

Received June 22, 2023 Revised October 24, 2023 Accepted October 25, 2023

Abstract

This research applied the linear programming model to analyze the allocation of organic fertilizer transport by InnoFarm Biotech Company Limited from the warehouses in three provinces, including Chanthaburi, Rayong and Trat, to seven distribution points, with the goal to minimize total transportation costs. The secondary data from relevant sources was employed while the problem was analyzed using the Solver function in Microsoft Excel. The results of this study informed a more efficient shipping allocation which is outlined as followed. Firstly, from the warehouse in Chanthaburi, the Company should ship 2,100 sacks of organic fertilizer to distribution point number 1, and 1,200 sacks to distribution point number 2. Then, from the warehouse in Rayong, 1,100 sacks of organic fertilizer must be shipped to the distribution point number 3 while the other 1,000 sacks, and 900 sacks, must be sent to distribution point number 4, and 5, respectively. Finally, from the warehouse in Trat, the shipment of 400 sacks, 800 sacks, and 600 sacks of organic fertilizer, must be allocated to the distribution point number 3, 6, and 7, respectively. The revised allocation strategy allowed all distribution locations to have the amount of products at their maximum capacity and also assisted the Company in reducing the transportation cost to 50,067 Thai Baht per week. According to the research, current operations does not employ any calculation tool in allocating the shipment of organic fertilizer. In fact, the Company mostly relies on existing experience and tend to transport products to distribution points located in the same province

at once in order to minimize travel distance and costs. However, such technique is perceived as inefficient transportation route management and costs 56,317 Thai Baht per week. In conclusion, the shipment allocation strategy developed from the findings of this research allows the InnoFarm Biotech Company Limited to reduce overall transportation costs by 6,250 Thai Baht (11 percent) per week, while also assists in the planning of organic fertilizer transport from warehouses to distribution points to be more appropriately and more efficient.

Keyword: Transportation Cost, Linear Programming, Optimization, Microsoft Excel Solve

Introduction

As organic food and non-chemical goods consumption have become a popular emerging trend in today's society, demand for organic fertilizer is perceived to expand at a highly fast pace owing to the fact that it is a crucial component of organic farming (Positioningmag, 2005). Organic fertilizer has numerous advantages. It not only improves the quality of the soil to suit a plantation, but it also causes the soil particles to become coagulated and well-structured, allowing for good ventilation, as well as efficient water holding and drainage. In addition, organic fertilizers increase nutrients in the soil, improve plants' ability to absorb nutrients, increase resistance ability to changes in soil acidity and base, and reduce the toxicity of some nutrients. Recent studies found demand for organic fertilizer among Thai farmers has been continuously increasing, yet there is a supply shortage on the production side, causing the need for organic fertilizer

imports from other countries. This fact is rather irritating especially when considering that Thailand has more than enough resources to produce organic fertilizer for farmers in the whole domestic market. As a result, the government implemented several stipulate measures in order to encourage agriculturists to self-produce and utilize organic fertilizer, as well as to encourage the private sector to commercialize more organic fertilizer. Government regulations are believed to play a key role in reducing organic fertilizer imports from other international markets, boosting the recycling economy, and propelling Thailand to the forefront of the region's organic fertilizer industry (Ratneetoo, 2009).

A significant challenge in the organic fertilizer industry being the transportation difficulties because the package of fertilizer is both large-sized and heavy, pushing the companies to plan every shipment efficiently in order to minimize cost of operations and be able to compete in this

industry. However, this research learned that the InnoFarm Biotech Company Limited has never implemented any quantitative technique or route planning in their shipping operations, yet relies on existing experience and strives to ship bulks of product to the distribution points located in the same province at once with an objective to minimize travel distance and costs. By following such approach, the Company has been unable to determine the appropriate amount of shipment per time, and the overall transportation cost is always relatively high. Refer to the Company's data from 2018 to 2021, the eastern region had the highest number of organic fertilizer sales compared to the other regions. The Company operates warehouses in three eastern provinces including Chanthaburi, Rayong, and Trat, where products from these three warehouses must be distributed to seven different sales sites. In detail, items from Chanthaburi warehouse must be shipped to distribution points number 1 – 3, products from Rayong warehouse are to be sent to distribution points number 4 – 6, and products from Trat warehouse must be shipped to a distribution point number 7. The total transportation cost was 56,317 Thai Baht per week. Therefore, this study aims to introduce an effective logistic

development plan for the InnoFarm Biotech Company Limited which could assist the Company in minimizing the overall transportation cost for organic fertilizer and establishing the efficient shipment allocation strategy. According to the recent research, Bungbua and Patsopa (2021) suggests that the linear programming model can be used as a guideline for solving logistics-related problems, as well as to inform decision-making and planning in transportation. This is in line with the study by Phosamrit and Thammaponphirat (2010) which also applied a linear programming model to determine an effective shipment routing with an ultimate goal to reduce overall transportation costs.

In the pursuit of the determine the optimal transportation costs, it becomes imperative to ascertain the quantity of organic fertilizer, which was originally based solely on previous transportation planning experience to be delivered from the company's various warehouses to distinct distributor locations to achieve the optimization, the data were collected from interviewing company manager. Specifically, these data encompassed the average transportation costs per sack from the company's warehouse to deliver to distributor destinations, as outlined in the figure below

Average shipping costs per sack								
Warehouse	Distribution points							
	Pootawan 1	Pootawan 2	Pootawan 3	Pootawan 4	Pootawan 5	Pootawan 6	Pootawan 7	Supply
Chanthaburi	6.25	7.50	8.75	10.00	11.25	8.75	10.00	5,000
Rayong	8.75	8.13	6.25	5.00	5.63	10.00	11.25	3,000
Trat	8.13	8.75	7.50	10.63	12.50	6.25	5.00	2,000
Demand	2,100	1,200	1,500	1,000	900	800	600	

Figure 1 Average shipping costs per sack.

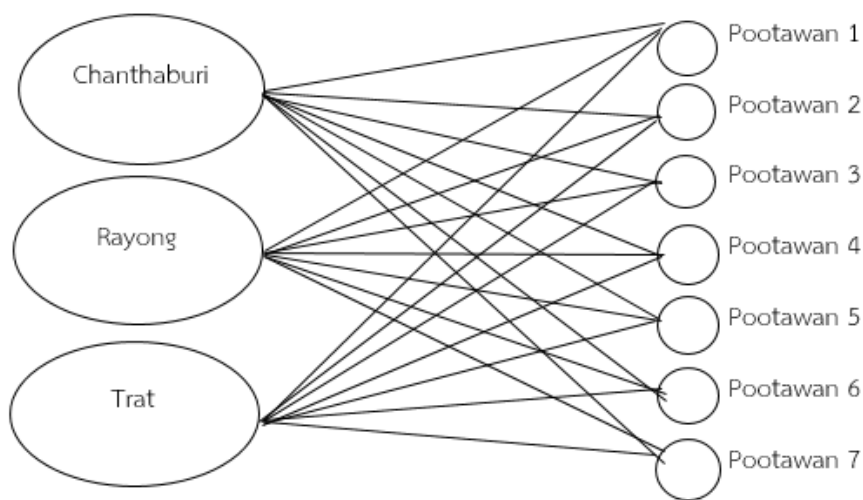


Figure 2 Illustration of the transportation network.

Research Objectives

The research aims to analyze and determine an efficient shipping strategy for organic fertilizer from the warehouses to points of sales in order to minimize the overall transportation costs. The transport models were designed and evaluated using linear programming.

Concept and Literature Review

In order to strategize and design the research process of this study, researchers

looked at data, concepts, theories, and relevant studies as summarized below.

1) Company overview

A case study company was the InnoFarm Biotech Company Limited, established in 2001 where its initial products were the herb-based insect repellents. Further in 2008, the Company expanded its business lines into the fertilizer industry by manufacturing both organic fertilizer products and other organic agricultural inputs. Another key

transformation took place in 2010 when the Company shifted its positioning to an expert in organic agriculture, producing every product needed in the organic farms such as organic fertilizers, bio-fertilizers, bio pesticides, as well as the bio-based substances for preventing and controlling plant diseases. The Company also operates a number of agricultural research centers and demonstration farms that are used for product development and quality control under the “InnoFarm” brand. Such practices assure quality of every product and increase customer satisfaction. The case study company is currently located in Muang Kanchanaburi district in the province of Kanchanaburi with the total operating area of approximately 200 rai (320,000 square meter). In terms of business performance, according to the Company report in 2018 – 2021, this study found that sales of distribution points located in the eastern region recorded the highest figure compared with sales of distribution points located in other regions of Thailand. In fact, the Company owns fertilizer warehouses in 3 different eastern provinces namely Chanthaburi, Rayong, and Trat, and these 3 warehouses are obligated to distribute organic fertilizer products to the distribution point located in 7 different

locations. (Tonghatta T., personal communication, May 12, 2022)

2) Transportation Problem

Transportation refers to a movement of goods from one source to another which creates a transporting route from the beginning of the supply chain to the customers. In fact, transportation is essential in every supply chain of production because goods always needed to be shipped out to different places for different consumers. Moreover, transportation is a key element that creates expenses within the supply chain, making such operation become a critical considering factor when the companies are looking for profit maximization, costs reduction, and efficiency optimization (Chopra and Meindl, 2003). The concept of transportation problem was developed using linear programming with an objective to solve resource allocation issues under a circumstance when there are several sources of resources and destinations (Hitchcock, 1941; Dantzig, 1951). In general, transportation problems may be presented in the format of linear programming model, and consist of 3 important components including sources, destinations, and transportation cost (Pongchairerks, 2017).

(1) Sources: refer to factories, manufactures or places that provide raw materials for producing one or many types of goods (supply). Generally, producers may acquire resources from multiple sources and each source possesses different capabilities in providing the raw materials.

(2) Destinations: refer to locations where demand for raw materials and / or

goods are acquired such as factories, markets, and warehouses. Destinations can be either a single site or multiple sites.

(3) Transportation Cost: refers to all expenses related to the transportation of goods from origin locations to destinations. Transportation costs vary between each destination depending on distance and geographical conditions of each origin point and destination.

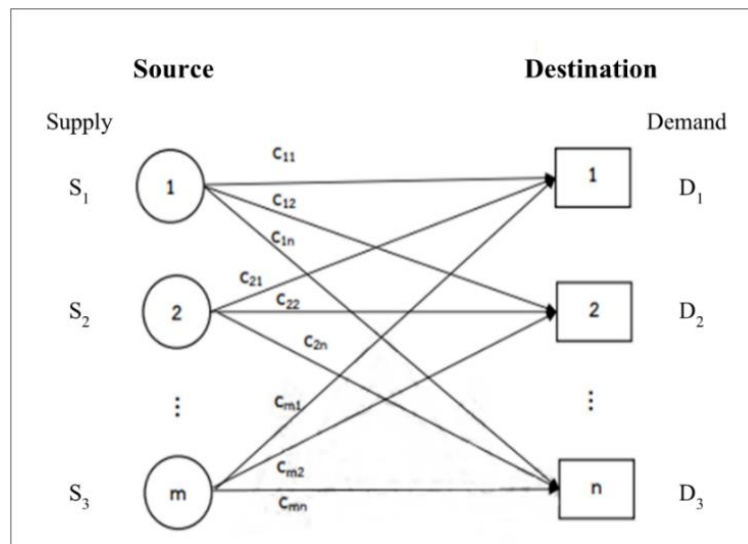


Figure 3 Transportation problem of goods shipment from m factories (source) to n warehouses (destination) where each factory and warehouse is located in different locations.

(Pongchairerks (2017). Linear Programming, Bangkok: Danex Inter corporation)

3) Concepts and Theories of Linear Programming

Linear programming is one of the well-known tools commonly used for planning any operation to achieve the best possible result in which the obtained must be consistent with the conditions set forth.

Examples of planning that can apply linear programming are such as planning of production activity to reach the minimized costs, and planning of operation to define the least number of employees needed (Hillier, 2010). In other terms, it is a mathematical method used to identify the

solution that leads to the optimal outcome, for example, to maximize the profit while minimizing overall operation costs (Jankovic, Eiselt and Sandblom, 2007). The method is active in various research fields including business, management, economics, as well as engineering while industries that regularly apply linear programming in their decision-making procedure are transportation, energy, communication and manufacturing. As a result, Fagoyinbo et al. (2011) draw the conclusion that the application of linear programming can help users in a variety of operations such as planning, route optioning, operational scheduling, tasks allocation, and operational design. In terms of transportation challenges, there are numerous studies that addressed issues about delivering products from manufacturers to distributors' warehouses and employed linear programming to determine the best allocation strategy, which helps to lower overall transportation costs (Khan, 2014).

Pongchairerks (2017) outlined three main elements of linear programming namely objective function, constraint, and decision variables. In addition, there are two sorts of problem considerations in the linear programming system: maximization problems and minimization problems. In

terms of definition, Chandrakantha (2008) defines three elements of linear programming as followed.

(1) Decision variables: Variables that must be taken into account in order to determine the best possible result, leading to the best possible solution / answer of the problem.

(2) Objective function: The objective of the problem such as maximizing the profit, minimizing cost, distance, time, et cetera.

(3) Constraint: The limitations or requirements of the problem which can be expressed as inequalities or equations in the decision variables.

Creating the linear programming model to represent the problem could be illustrated as followed:

Objective Function:

$$\text{Max (Min): } Z = c_1X_1 + c_2X_2 + \dots + c_nX_n$$

Constraints:

$$a_{11}X_1 + a_{12}X_2 + \dots + a_{1n}X_n (\leq, =, \geq) b_1$$

$$a_{21}X_1 + a_{22}X_2 + \dots + a_{2n}X_n (\leq, =, \geq) b_2$$

$$a_{m1}X_1 + a_{m2}X_2 + \dots + a_{mn}X_n (\leq, =, \geq) b_m$$

Variables: (Variable limitations)

$$X_1, X_2, \dots, X_n \geq 0$$

Substitutions:

$X_1, X_2, \dots, X_n$ represent decision variables

$C_1, C_2, \dots, C_n$	represent the coefficient of variable X in objective function
a_{ij}	represent the coefficient of variables in constraint function
b_i	represent a limited quantity of each resource

4) Excel Solver for solving linear programming problems

Solver is an optimization tool used in the calculation of linear programming in order to determine the best possible answer for the problem. Given conditions and constraints, the tool can achieve the optimum result within the specified time (Limpanawanich, 2019)

Using linear programming to overcome any challenge is considered an optimization of problem-solving as the method is promised to present the best possible answer under the given conditions and constraints. While Microsoft Excel being a decent software for analyzing, calculating, and managing data in the spreadsheet format, it provides the add-in function called “Solver”, which is highly useful in solving the linear programming models.

However, a significant limitation of this function is it can only solve the problems that contain less than 200 decision variables. The two main tools for solving linear programming models, SolverStudio and OpenSolver, were developed by Andrew J. Mason and are available for free download and installation. SolverStudio requires users to have a certain level of knowledge about computer languages. On the other hand, OpenSolver is comparable to the Solver function and can be used to solve linear programming models with any number of decision variables (Mason and Dunning, 2010; Mason, 2012).

In the case where a linear programming model consists of two decision variables, the results can be obtained by using the Graph Method. However, studies suggested the Simplex Method when solving a model that contains more than two decision variables as it is the most effective, systematical, and efficient approach. The principle behind the Simplex Method is based on the theory of matrices which is about moving the objective function from one feasible solution to another with a better solution. Such method is considerably efficient as it does not involve all possible answers in the model (Onwubiko, 1999; Pongchairerks, 2017).

Related Research

This study reviews a wide range of related research in order to identify research approach and utilizable

information from studies that are attempting to address similar problems.

Table 1 below describes a summary of related research reviews.

Table 1 Summary of related research reviews

Authors	Objective	Tools	Research outcome
Khan (2014)	Using Excel Solver and Linear Programming to determine the most appropriate transportation cost.	Linear Programming / Excel Solver	The research found the most suitable solution that serves to minimize transportation cost and maximize profit under the given conditions and constraints.
Aboelmagd (2018)	Applying Excel Solver and Linear Programming in the decision-making procedures for most appropriate operation costs.	Linear Programming / Excel Solver	Achieved research objective as the calculation can identify the lowest costs of operation within the shortest time.
Theerarangsi kul and Wangwatcharakul (2021).	To design a tool for planning a soil delivery operation with limited resources, assisting the company to complete every project within the given due date at the lowest costs of operation.	Linear Programming / Excel Solver	The usage of excel solver function and mathematical model enabled the company to attain the most efficient logistic planning strategy which reduces both project duration and total logistics cost.
Bungbua and Patsopa (2021)	To analyze the allocation of palm oil transportation from planted areas to the place of purchase in Sa Kaeo with the objective to find the lowest total cost allocation of palm oil transportation.	Linear Programming / Excel Solver	The developed model can be used to analyze and compare the allocation of palm oil transportation under given conditions and constraints, hence, assisting the company to identify the best option at the lowest delivery costs.

To conclude, the review of concepts, theories, and related research ensures that linear programming can be applied to the problem-solving process in a

variety of contexts. Hence, this research applied linear programming method by using Microsoft Excel Solver in order to identify the best possible shipping

allocation for organic fertilizer products from three warehouses in the eastern region to seven distribution sites at the lowest overall costs of transportation.

Research Methodology

This study employed a quantitative research method where data is collected from the secondary source: the Company's report on transport operation. The linear programming models were developed using Microsoft Excel Solver. In details, this study consists of four key research processes as discussed below.

Problem Identification: To identify current transportation costs of each delivery operation, data about the current organic fertilizer products shipping strategy

was observed, analyzed and described as illustrated in Table 2. The overall cost of transportation was accounted to 56,317 Thai Baht per week, as shown in the following breakdown.

(1) From Chanthaburi warehouse to distribution point number 1 – 3, costs of transportation were equaled to $(2,100 \times 6.25) + (1,200 \times 7.5) + (1,500 \times 8.75) = 35,250$ Thai Baht.

(2) From Rayong warehouse to distribution point number 4 – 6, costs of transportation were equaled to $(1,000 \times 5.00) + (900 \times 5.63) + (800 \times 10.00) = 18,067$ Thai Baht.

(3) From Trat warehouse to distribution point number 7, costs of fertilizer transportation were equaled to $600 \times 5.00 = 3,000$ Thai Baht.

Table 2 Current organic fertilizer products delivery allocations

Warehouse	Distribution Points							Supply
	Pootawan 1	Pootawan 2	Pootawan 3	Pootawan 4	Pootawan 5	Pootawan 6	Pootawan 7	
Chanthaburi	2100 (6.25)	1200 (7.5)	1500 (8.75)					5000
Rayong				1000 (5.00)	900 (5.63)	800 (10.00)		3000
Trat							600 (5.00)	2000
Demand	2100	1200	1500	1000	900	800	600	

Define Variables and Modeling Linear Programming Problems: Based upon the thorough analysis of data about costs of transportation, demand, and available

supply, the linear programming model was developed by using the Solver function in Microsoft Excel. Further, the variables were defined as discussed below.

Warehouse	Distribution points							
	Pootawan 1	Pootawan 2	Pootawan 3	Pootawan 4	Pootawan 5	Pootawan 6	Pootawan 7	Supply
Chanthaburi	6.25	7.50	8.75	10.00	11.25	8.75	10.00	5,000
Rayong	8.75	8.13	6.25	5.00	5.63	10.00	11.25	3,000
Trat	8.13	8.75	7.50	10.63	12.50	6.25	5.00	2,000
Demand	2,100	1,200	1,500	1,000	900	800	600	

Figure 4 Data on average transportation cost (Thai Baht per sack), demand (sack), and available supply (sack)

Defining variables and creating linear programming model

X_{11} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 1

X_{12} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 2

X_{13} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 3

X_{14} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 4

X_{15} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 5

X_{16} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 6

X_{17} represents a transportation of organic fertilizer products from Chanthaburi warehouse to a distribution point 7

X_{21} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 1

X_{22} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 2

X_{23} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 3

X_{24} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 4

X_{25} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 5

X_{26} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 6

X_{27} represents a transportation of organic fertilizer products from Rayong warehouse to a distribution point 7

X_{31} represents a transportation of organic fertilizer products from Trat warehouse to a distribution point 1

X_{32} represents a transportation of organic fertilizer products from Trat warehouse to a distribution point 2

X_{33} represents a transportation of

organic fertilizer products from Trat warehouse to a distribution point 3

X_{34} represents a transportation of organic fertilizer products from Trat warehouse to a distribution point 4

X_{35} represents a transportation of organic fertilizer products from Trat warehouse to a distribution point 5

X_{36} represents a transportation of organic fertilizer products from Trat warehouse to a distribution point 6

X_{37} represents a transportation of organic fertilizer products from Trat warehouse to a distribution point 7

Objective Function: to identify an allocation strategy for a transportation of organic fertilizer products from 3 warehouses to 7 distribution points at the lowest overall costs of transportation.

$$\begin{aligned} \text{Min } Z = & 6.25X_{11} + 7.50X_{12} + 8.75X_{13} + 10X_{14} + 11.25X_{15} + 8.75X_{16} + 10X_{17} \\ & + 8.75X_{21} + 8.13X_{22} + 6.25X_{23} + 5X_{24} + 5.63X_{25} + 10X_{26} + 11.25X_{27} + \\ & 8.13X_{31} + 8.75X_{32} + 7.50X_{33} + 10.63X_{34} + 12.50X_{35} + 6.25X_{36} + 5X_{37} \end{aligned}$$

Constraints:

Supply constraints

$$X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + X_{17} \leq 5,000 \quad (1)$$

$$X_{21} + X_{22} + X_{23} + X_{24} + X_{25} + X_{26} + X_{27} \leq 3,000 \quad (2)$$

$$X_{31} + X_{32} + X_{33} + X_{34} + X_{35} + X_{36} + X_{37} \leq 2,000 \quad (3)$$

Demand constraints

$$X_{11} + X_{21} + X_{31} = 2,100 \quad (4)$$

$$X_{12} + X_{22} + X_{32} = 1,200 \quad (5)$$

$$X_{13} + X_{23} + X_{33} = 1,500 \quad (6)$$

$$X_{14} + X_{24} + X_{34} = 1,000 \quad (7)$$

$$X_{15} + X_{25} + X_{35} = 900 \quad (8)$$

$$X_{16} + X_{26} + X_{36} = 800 \quad (9)$$

$$X_{17} + X_{27} + X_{37} = 600 \quad (10)$$

Transportation constraints

$$X_{ij} \geq 0 \quad (11)$$

To clarify, constraint number (1), (2), and (3) are concerning about available quantity of organic fertilizer products to be delivered to each distribution point. Further, constraint number (4), (5), (6), (7), (8), (9), and (10) are concerning about quantity demand for organic fertilizer products at each distribution point. Finally, constraint number (11) requires that all decision variables be non-negative number.

Data Validation: Analyzes the gathered data through a review of

concepts, theories and related research about transportation problem, linear programming, and using Excel Solver in an optimization of linear programming problems. Based on reviewed concepts and relevant studies, there are research methods that can be applied in identifying a transport allocation strategy for organic fertilizer products in order to meet the lowest overall cost of transportation. Figure 5 demonstrates the processes of designing a research method.

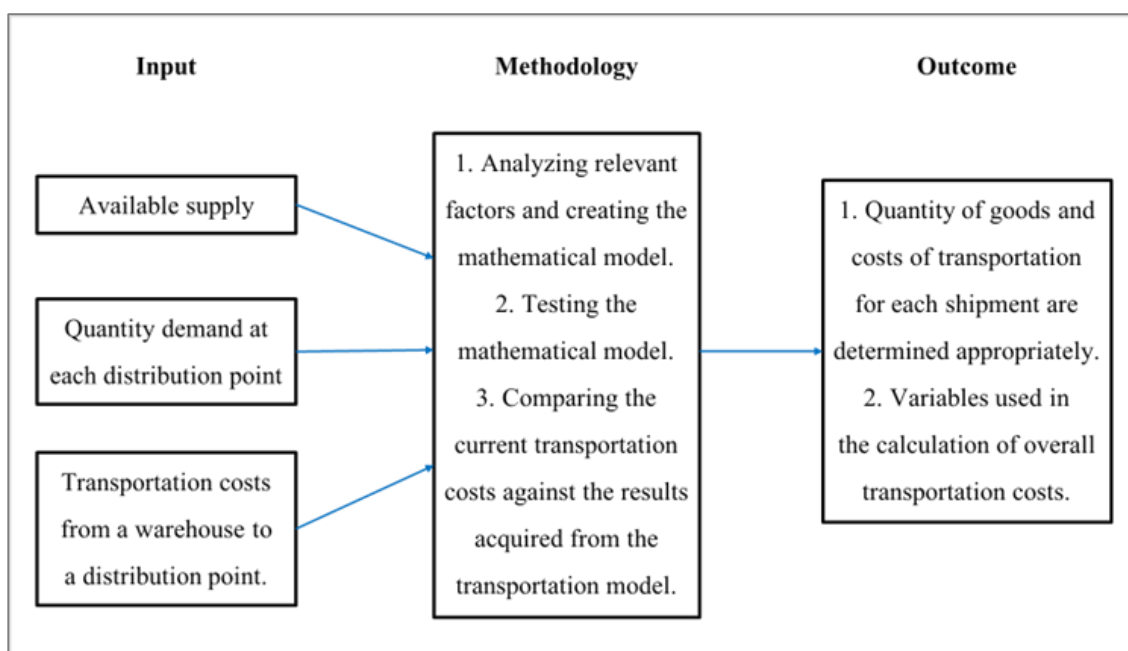


Figure 5 Processes of designing a research method

Solver Implementation: Employing the linear programming method in Excel Solver to analyze the gathered data and identify the possible lowest transportation cost under the given limitations and

constraints. The results from the linear programming model that help to determine the most possible answer are shown on Figure 6 and Figure 7.

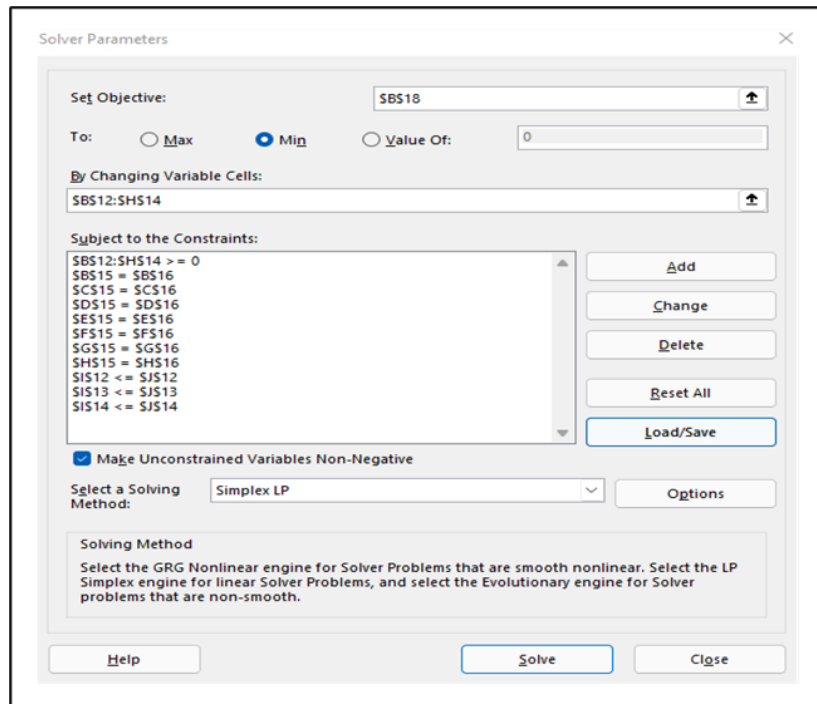


Figure 6 Solver implementation to calculate for decision variables, objective function, and constraints

shipping plan									
Warehouse	Distribution points							TotalOut	Supply
	Pootawan 1	Pootawan 2	Pootawan 3	Pootawan 4	Pootawan 5	Pootawan 6	Pootawan 7		
Chanthaburi	2,100	1,200	-	-	-	-	-	3,300	5,000
Rayong	-	-	1,100	1,000	900	-	-	3,000	3,000
Trat	-	-	400	-	-	800	600	1,800	2,000
Total-in	2,100	1,200	1,500	1,000	900	800	600		
Demand	2,100	1,200	1,500	1,000	900	800	600		
Total Shipping Cost	฿	50,067.00							

Figure 7 The results of an analysis of organic fertilizer transport allocation from warehouses to distribution points

Figure 7 displays results of data analysis using linear programming and Solver function in Microsoft Excel in order to determine the best possible shipping plan for organic fertilizer products. The results suggest that the warehouse in Chanthaburi province should delivery 2,100 sacks of organic fertilizer to the distribution point number 1 (Pootawan 1), and delivery 1,200 sacks to the distribution point number 2 (Pootawan 2). Moving on to shipping plans for the warehouse in Rayong province, the calculation informs that the organic fertilizer of 1,100 sacks, 1,000 sacks, and 900 sacks must be shipped to the distribution point number 3 (Pootawan 3), 4 (Pootawan 4) and 5 (Pootawan 5), accordingly. Finally, the warehouse in Trat province should be delivering 400 sacks of organic fertilizer to distribution point number 3 (Pootawan 3), 800 sacks to distribution point number 6 (Pootawan 6), and 600 sacks to the distribution number 7 (Pootawan 7). The discussed shipping plans above allowed each distribution point to store the products at their maximum capacity, meet the quantity demand, while also assisted the Company in reducing the transportation costs to 50,067 Thai Baht per week.

Given the fact that current transport operations at the case study company did

not apply any calculation method in designing the shipping plan, therefore lack of effective route planning and could not estimate the appropriate quantity of organic fertilizer per delivery. The Company relies on established experience and manages to transport organic fertilizer products to distribution points located in the same province at once in order to minimize travel distance and costs. Such method costs 56,317 Thai Baht per week for overall transportation expenses. On the other hand, results of an analysis of linear programming model show that the Company could reduce the operation costs by 6,250 Thai Baht (11 percent) per week, leading the overall transportation costs to the lowest figure at 50,067 Thai Baht per week. Furthermore, by using the linear programming optimization, the InnoFarm Biotech Company Limited was able to allocate the quantity of each organic fertilizer shipment effectively. Table 3 describes different results achieved from current operations and linear programming.

Table 3 Comparison of results from the current operations and results from linear programming

Results of current operations (relying on experience and travel distance management)	Results from linear programming model	Transportation costs
Ship organic fertilizer from the Chanthaburi warehouse amounted to 2,100 sacks, 1,200 sacks, and 1,500 sacks to the distribution point number 1, 2, and 3, accordingly. The transportation costs were 35,250 Thai Baht per week.	Ship organic fertilizer from the Chanthaburi warehouse amounted to 2,100 sacks to distribution point number 1, and 1,200 sacks to distribution point number 2. The transportation costs per week were 22,125 Thai Baht.	Transportation costs decreased by 13,125 Thai Baht (37.23 percent) per week.
Ship organic fertilizer from the Rayong warehouse amounted to 1,000 sacks, 900 sacks, and 800 sacks to the distribution point number 4, 5, and 6, accordingly. The transportation costs were 18,067 Thai Baht per week.	Ship organic fertilizer from the Rayong warehouse amounted to 1,100 sacks, 1,000 sacks, and 600 sacks to the distribution point number 3, 4, and 5, accordingly. The transportation costs were 16,942 Thai Baht per week.	Transportation costs decreased by 1,125 Thai Baht (6.23 percent) per week.
Ship 600 sacks of organic fertilizer from the Trat warehouse to the distribution point number 7. The transportation costs were 3,000 Thai Baht per week.	Ship organic fertilizer from the Rayong warehouse amounted to 400 sacks, 800 sacks, and 900 sacks to the distribution point number 3, 6, and 7, accordingly. The transportation costs were 11,000 Thai Baht per week.	Transportation costs increased by 8,000 Thai Baht (266.67 percent) per week.
The overall transportation costs were 56,317 Thai Baht per week.	The overall transportation costs were 50,067 Thai Baht per week.	The overall transportation costs decreased by 6,250 Thai Baht (11.10 percent) per week.

Results Discussion and Conclusion

This study aimed at analyzing the allocation strategy of organic fertilizer transportation from warehouses to distribution points in order to determine the new operation method that could help the Company to achieve the lowest transportation costs. The research applied quantitative method and gathered data from the secondary source such as the Company's report on transportation expenses. The linear programming models were then created using the Microsoft Excel Solver function and the results of a comprehensive analysis are discussed below.

By using Microsoft Excel solver to analyze the linear programming model, new shipping plans were identified and believed to assist the Company in minimizing the overall transportation costs. First of all, the warehouse in Chanthaburi province should delivery 2,100 sacks of organic fertilizer to the distribution point number 1, and another 1,200 sacks to the distribution point number 2. As for the warehouse in Rayong province, the Company is suggested to ship organic fertilizer amounted to 1,100 sacks, 1,000 sacks, and 900 sacks to the distribution

point number 3, 4, and 5, respectively. Finally, ship 400 sacks, 800 sacks, and 600 sacks of organic fertilizer from the warehouse in Trat province to a distribution point number 3, 6, and 7, respectively. According to the linear programming model, the discussed shipping strategies could assist the Company in estimating the appropriate inventory and quantity demand at each distribution point. The new shipping strategy could also lead to a reduction transportation costs which allow the InnoFarm Biotech Company Limited to meet the lowest overall transportation costs at 50,067 Thai Baht per week. Compared to the current shipping operation where overall transportation costs were 56,317 Thai Baht per week, the new shipping plan could reduce the transportation costs by 6,250 Thai Baht (11.10 percent) a week.

The analysis of linear programming model leads to a more effective allocation of organic fertilizer transportation. As the analysis considered all expenses related to a transportation of organic fertilizer from 3 warehouses in the eastern region to 7 distribution points, the transportation activities that take place between nearby warehouses and distribution points were evaluated before activities between warehouses and distribution points that are

far apart. Research objectives were set to minimize overall transportation costs and enhance efficiency for Company's products transport operations, allowing the InnoFarm Biotech Limited Company to acquire competitive advantage in regard to transportation costs. This is in line with several pieces of research such as Khan (2014) which implemented linear programming model to calculate the best possible transportation costs for products delivery with Excel Solver, and was able to reduce overall costs and increase profit under given constraints. Bungbua and Patsopa (2021) also developed a linear programming model which analyzed and compared the allocation of palm oil transportation under given conditions and constraints, hence, assisting the company to identify the best option at the lowest delivery costs. Similarly, Aboelmagd (2018) achieved their desire research objective as the calculation created with Excel Solver and linear programming can identify the lowest costs and shortest time of operations. Last but not least, Theerarangsikul and Wangwatcharakul (2021) created a tool to aid in planning a soil delivery operation with limited resources, helping the firm to execute every project by the deadline while incurring the fewest operational expenses.

The organization was able to achieve the most effective logistic planning approach, which shortens project duration and lowers overall logistics costs, through the use of an Excel solver function and mathematical model. To conclude, this research is consistent with previous relevant studies as the findings show that linear programming can be applied to solve challenges relating to expenses in transport operations in order to achieve the lowest overall transportation costs.

Recommendations

This study applied linear programming model to analyze the transport operations of organic fertilizer from warehouses in the eastern region to different distribution points. The objective achieved was to identify the best possible shipping plans which require the lowest overall transportation costs under the given constraints and limitations. The results of this study may be applied by stakeholder such as government organizations, businesspeople and interested parties in their effort to develop an efficient transportation planning and management for the purpose of achieving competitive advantage, particularly with regard to transportation costs. However, this research only took into account information from a

single secondary source, the InnoFarm Biotech Company Limited, where the analysis focused on data about the available supply, the quantity demanded at distribution points, and the costs of transport operations for delivering organic fertilizer between warehouses and distribution points situated in the provinces of the eastern region. Therefore, it is advised that future research consider data from other areas or regions in order to contribute more to the literature on goods transportation planning and management systems. Finally, the Company is suggested to implement the record-keeping system or information technology that assist in estimating and tracking quantity demand at each distribution points, allowing for a more effective allocation of goods delivery to better meet demand of the distribution points.

References

- Aboelmagd, Y.M. (2018). Linear Programming Applications in Construction Sites. *Alexandria Engineering Journal*, 57(4), 4177-4187.
- Bungbua, P., and Patsopa, Y. (2021). Using a Linear Programming Model to Analyze the Allocation of Palm Oil Transportation from Planted Areas to the Place of Purchase in Sa Kaeo Province, *North Eastern University Academic and Research Journal*, 11(3), 258-272
- Chandrakantha, L. (2008). *Using Excel Solver in optimization problems*. Mathematics and Computer Science Department. New York.
- Chopra, S. and Meindl, P. (2003). *Supply Chain Management: Strategy, Planning, and Operations (Translation: Vithaya Suharitdumrong)*. Second edition. Bangkok: Pearson Education Indochina.
- Dantzig, G. B. (1951). *Application of the Simplex Method to a Transportation Problem: in T.C. Koopmans (ed.) Activity Analysis of Production and Allocation*, John Wiley & Sons, New York, Pages 359-373.
- Fagoyinbo, I. S., Akinbo, R. Y., Ajibode, I. A. and Olaniran, Y. (2011). Maximization of Profit in Manufacturing Industries Using Linear Programming Techniques: Geepee Nigeria Limited. *Mediterranean Journal of Social Sciences*, 2(6), 97 - 105.

- Hillier, F. S. (2010). *Introduction to Operations Research*, (Ninth Edition), Boston: McGraw-Hill Higher Education.
- Hitchcock, F. L. (1941). The Distribution of a Product from Several Sources to Numerous Localities. *Journal of Mathematical Physics*, 20, 224 - 230.
- Jankovic, O., Eiselt H.A., and Sandblom C. L. (2007). *Linear Programming and Its Applications*. Springer-verlag, Berlin Heidelberg, 2007.
- Khan M. A. (2014). Transportation Cost Optimization Using Linear Programming. *International Conference on Mechanical, Industrial and Energy Engineering* (2014), 25 - 26 December, 2014, Khulna, BANGLADESH.
- Limpanawanich, S. (2019). *An Analysis of Distribution Center Location for Southern Zone: A Case Study of a Private Company*. (Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Industrial Management). Songkla: Prince of Songkla University.
- Mason, A. J. (2012). OpenSolver – An open source Add-in to solve linear and integer programmes in Excel. In D. Klatte, H.-J. Lüthi, & K. Schmedders (Eds.), *Operations research proceedings 2011* (pp. 401–406). Springer.
- Mason, A. J., and Dunning, I. (2010). Opensolver: open source optimisation for excel. In *Proceedings of the 45th Annual Conference of the ORSNZ* (pp. 181-190). Operations Research Society of New Zealand.
- Onwubiko, O. C. (1999). *Introduction to Engineering Design Optimization*. Upper Saddle River, NJ: Prentice-Hall.
- Phosamrit, N. and Thammaponphirat, W. (2010). A Mathematical Model for Inventory-routing Problem. *The Journal of King Mongkut's University of Technology North Bangkok*, 20 (3), 544-551.
- Pongchairerks, P. (2017). *Linear Programming*, Bangkok: Danex Inter corporation.
- Positioningmag. (2005). *Organic Fertilizer: Rising Amid the Natural Goods*

Consumption Trend (Online).

Retrieved May 30, 2005, from

<https://positioningmag.com/115243>

4

Ratneetoo, B. (2009). Organic Fertilizer Improves Deteriorated Soil, *Princess of Naradhiwas University Journal*, 1(2), 1-16.

Theerarangsikul, T. and Wangwatcharakul, W. (2021). Designing of a Planning and Scheduling Tool for Earth Moving Operation under Limited Resource, *Thai Journal of Operations Research*, 9(1), 142-152.

Tonghatta, T. (2022, May 12). General Manager. Personal Communication.

