A MULTI-OBJECTIVE OPTIMIZATION OF THE FLEET SIZING PROBLEM FOR THAI RICE EXPORTER: A CASE STUDY

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Abstract

This paper aims at providing the multi-objective optimization model which deals with the fleet sizing problem for a rice exporting company in Thailand. The company transports the rice from Northern area to Bangkok seaport with the distance of 300 km. The fleet sizing decision is made based on three objectives including 1) minimizing total fleet cost, 2) minimizing total environmental impact, and 3) maximizing the customer satisfaction (demand) simultaneously. The time uncertainty of unloading process at the seaport is considered as a primary factor to determine fleet size. The methodology consists of 3 main steps. In the first step, the decision problem is formulated as a multi-objective, integer, non-linear programming minimised simultaneously. The number of truck in the fleet is the finding variable. In the second step, the significant data is collected from the company who collect the rice from local area and transport them to the seaport. The data of unloading process at the seaport is also collected to identify the total travelling time of the truck. In the last step, the model is verified and validated using the collected data from company.

Keywords:
Fleet sizing, Multi-objective optimization, Time uncertainty of unloading process

Introduction

Globally, the value of exports and imports of agricultural commodities has increased considerably after 1970 as shown in Figure 1 [1]. Much of this growth has been driven by increased import demand from middle-income developing countries. This phenomenon drives the agriculture-based counties to change to their logistic infrastructure, especially in transportation system, to facilitate the domestic trading and the export growth. Thailand, a strong tradition of rice production, has the fifth-largest amount of land under rice cultivation in the world and is the world's second largest exporter of rice [2]. It enhances continuously its transportation system as one of primary mechanisms to improve its economic and social stability. Road network system is improved to link many agricultural areas, locating in upper central provinces and middle of Thailand, with the trading hubs and exporting seaports. Nowadays, two main seaports are Bangkok seaport and Laemchabang seaport play an important role for exporting their local rice to many parts of the world such as Africa, Middle East, USA, and others. In many cases, the rice exporters collect rice from farmers and subcontract the third-party logistics provider to transport the rice to the seaport for forwarding by shipping to the customer's destination.

Third party logistics providers typically specialize in transportation services that can be customized to customers' needs. However, as the steadily increase in the exporting amount, many rice exporters has faced with the decision to perform a transportation task by themselves. There are three main aspects which need to be considered in decision of transferring toward fleet ownership. They include 1) cost aspect, 2) environmental aspect, and 3) service quality. Firstly, the cost of fleet ownership can be reduced as the market growth. This is due to the ownership in truck fleet can improve the truck utilization and the transportation cost could be reduced. However, it is necessary to carefully compare between life cycle cost of fleet ownership and that of outsourcing this task to third party logistics provider. Secondly, the truck ownership can give the opportunity of reducing the environmental impact. Today, the environmental issue induce many companies to initiate the project of reduction in environmental burden as social responsibility. Transportation is considered as one of significant driver to improve the environmental performance. As a result, transportation should be considered as a key factor of making decision on fleet ownership. Finally, the ownership of truck provides the opportunity of improving the service level to the customer. Service quality is emphasized on the sending the product to customer on the right time and the right quantity. The truck ownership provides the company to control many factors which may affect the quality of service. In the case of rice exporter, the time uncertainty of unloading rice at seaport makes the company and its logistics provider unable to control the shipping time to customer. Thus, the ownership of truck fleet provides the company to justify the fleet size to accommodate the uncertainty of unloading process at the seaport.

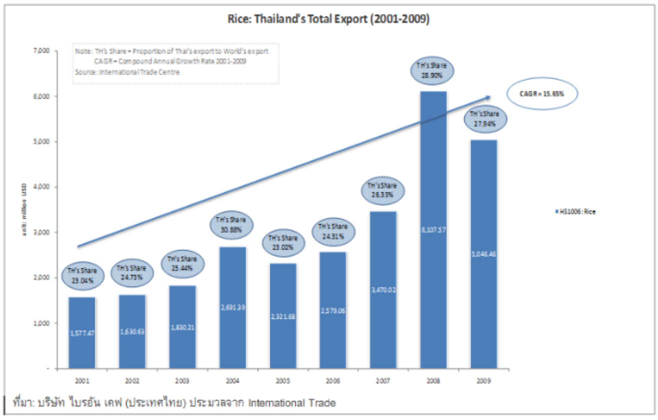

Figure 1: Thailand's growth in rice export from 2001 to 2009 [2]

As a consequence, this research aims to propose a decision support model for rice exporter to make the decision of whether having their own truck fleet or outsourcing this task to third party provider. The multi-objective optimization consists of three aspects including the minimization of total cost, the minimization of environmental impact, and the maximization of service quality. The decision is made base on the number of trucks in transportation fleet. The organization of the paper consists 4 main sections including introduction, methodology, application, and conclusion. The model development is presented in the methodology section which is followed by this section. Then the application section shows the results of the model applications. Finally, the conclusion section summarises the content and a future work of the paper.

Figure 2: Rice collected at local area in northern part of Thailand

Figure 3: Truck transporting rice from local area to Bangkok seaport

Methodology

In order to achieve the objective of the research, the methodology framework as shown in **Error! Reference source not found.**4 is proposed.

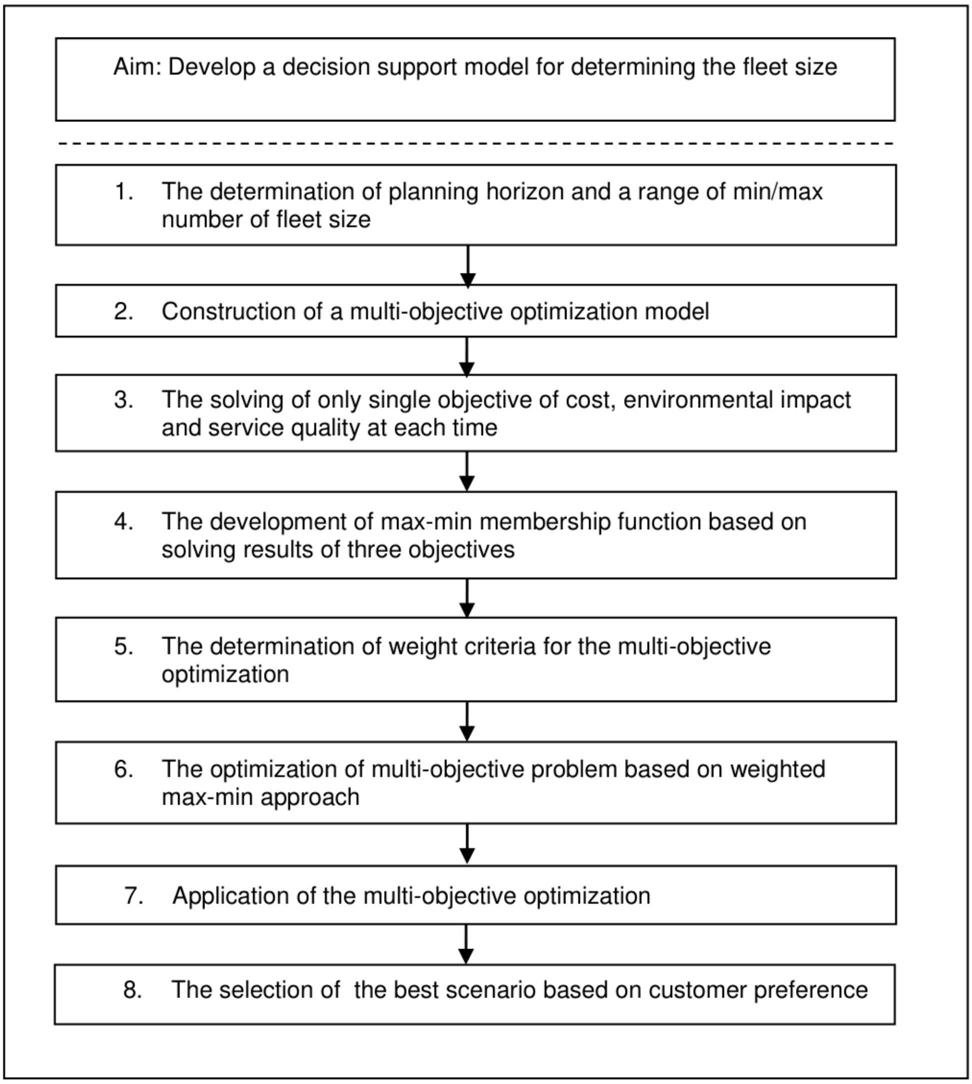

Figure 4: The decision support model for determining the fleet size

Step 1: A planning horizon and a range of number of leasing during planning horizon determination

In the first step, a planning horizon and a range of min/max number of fleet size are determined. The data of rice transportation is collected from the company. This includes the data of outsourcing the transportation task to the service provider and the data of owning transportation system. As described by the company, 7 trucks should be the minimum number of fleet size and 35 trucks is the maximum number. In addition, the functional unit of 10 years are defined as service span of trucks.

Step 2: Construction of mathematical model

The second step concerns about the development of a multi-objective optimization model. The formulation of the mathematical model is carried out based on the mixed integer non-linear programming to identify the values of these decision variables. Three objectives of the model which are the minimization of total leasing costs, the minimization of environmental impact, and the maximization of service quality are formulated. To achieve these goals, several main constraints need to be taken into account. The mathematical model is constructed based on the three following components which are 1) decision variable 2) objective functions and 3) constraints.

Decision variable
N = Number of trucks in fleet

Objective function

2.1 The minimization of the cost
This objective function is to ensure that the fleet size model generates minimum total cost and the cost of owning the truck fleet is less than that of the outsourcing logistics service. This cost components are based on the Life Cycle Cost (LCC) approach, consisting of 1) cost of product acquisition, 2) cost of operation including driver's salary, energy consumption, maintenance, and other costs, and 3) cost at end-of-life stage. It can be described in mathematical form as Equation 1.

$$Min\ C_t = N \times (C_a + (C_d + C_e + C_m + C_o) + C_{eol}) \quad (1)$$

Where

Decision variables:

N	= Number of truck in fleet;
C_a	= Cost of truck acquisition (baht);
C_d	= Cost of driver's salary (baht);
C_e	= Cost of energy consumption (baht);
C_m	= Cost of maintenance (baht);
C_o	= Other cost such as insurance and tax (baht);
C_{eol}	= Cost of end-of-life (baht);

2.2 The minimization of the environmental impact

This objective function is to ensure that the fleet size model generates minimum environmental impact and the environmental impact of owning the truck fleet is less than the outsourcing logistics service. The environmental impact component based on the simplified LCA approach is proposed by Manmek [3]. The total cycle environmental impact of the leasing system consists of 1) environmental impact of product acquisition and 2) environmental impact of operation including energy consumption, spare parts, and 3) environmental impact at the end-of-life stage. It can be described in mathematical form as Equation 2.

$$Min\ EI_t = N \times (EI_a + (EI_e + EI_m) + EI_{eol}) \quad (2)$$

Where

Decision variables:

N	= Number of truck in fleet;
EI_a	= Environmental impact of truck acquisition (point);
EI_e	= Environmental impact of energy consumption (point);
EI_m	= Environmental impact of maintenance (point);
EI_{eol}	= Environmental impact of end-of-life (point);

2.3 The maximization of the service quality

This objective function is to ensure that the fleet sizing model provides the maximum service quality. This function is to describe the uncertainty in the unloading process at the seaport. This process can take from 1 day to 5 days based on the traffic condition and the delay of processes. The uncertainty in this process affects the number of trucks in fleet. The more truck is congested during the shipping process, the more spare truck is required in the fleet size.

Step 3: The solving of single objective of cost, environmental impact, and service quality at each time

Step 3 concerns about the solving of single objective of cost, environmental impact, and service quality at each time. After the mathematical model is developed in the previous step, the single objective of cost, environmental impact and service quality is solved separately. The solving is based on two types of objective functions which are minimization and maximization. The cost and environmental impact of the system are aimed to be minimised. To the contrary, the service quality is expected to be maximised. The results of this stage are the minimum and maximum values of each objective function.

Step 4: The development of the max-min membership function based on the solved results of three objectives

In Step 4, the max-min membership function is developed based on the solved results of three objectives [4]. The membership function of an objective determines the closeness of its optimum value to the target. This linear function presents the optimal value existing at any point between minimum and maximum values. Among the set of optimal solutions, the best and worst values for each objective is defined as Z_k^+ and Z_k^- respectively. They are shown in Table 1.

Table 1: The best and worst value for each type of objective function

Objectives	Max and min values for each objective		
	Z_k^-	Z_k^+	Z_k^-
Minimization goal	-	$\min(Z_k(x))$	$\max(Z_k(x))$
Maximization goal	$\min(Z_k(x))$	$\max(Z_k(x))$	-

Linear membership function of an objective for minimizing is calculated from Equation 3 and the linear membership function of an objective for maximizing is calculated from Equation 4.

The linear memberships function for minimization goal:

$$\mu_{zk}(x) = \left\{ \begin{array}{ll} 1 & if\ Z_k(x) < Z_k^+ \\ (Z_k^- - Z_k(x))/(Z_k^- - Z_k^+) & if\ Z_k^+ \le Z_k(x) \le Z_k^- \\ 0 & if\ Z_k(x) > Z_k^- \end{array} \right\} \qquad (3)$$

The linear memberships function for maximization goal:

$$\mu_{zk}(x) = \left\{ \begin{array}{ll} 1 & if\ Z_k(x) > Z_k^+ \\ (Z_k(x) - Z_k^-)/(Z_k^+ - Z_k^-) & if\ Z_k^- \le Z_k(x) \le Z_k^+ \\ 0 & if\ Z_k(x) < Z_k^- \end{array} \right\} \qquad (4)$$

Where $\mu_{zk}(x)$ is the linear membership function of objective *k*

Z_k^+ and Z_k^- are the best and worst values of objective *k*.

Step 5: The determination of weights for linear membership functions

Step 5 is to determine the weight of linear membership functions for the multi-objective optimization. The weight of the objective function (w_k) is the value which reflects the relative importance of the objective function. The greater the value of the weight, the more important the objective function. Likewise, the lesser value of weight represents a lower importance of the objective function. The weight of objectives (w_k) is required for the multi-objective optimization in order to set the priority for the trading off among the linear membership functions.

Step 6: The optimization of the linear membership functions to identify the optimal values

The optimization of membership functions is conducted simultaneously in this stage. This optimization can be achieved by the weighted max-min model [5]. This approach uses the ratio of achievement as a parameter to present the closeness of the function's values to the predetermined objective values. This ratio is defined as λ (lambda). The objective of this model is to maximise the value of λ to ensure that every function's value approaches as close as possible to its objective value. It is based on the consideration of weight for each objective. This model is formulated as shown in Equation 5 to Equation 9:

$$Max \quad \lambda \tag{5}$$

Subject to:

$$\mu_{zk}(x) \geq \lambda w_k \quad k = 1,....,q \tag{6}$$

$$\lambda \in [0,1] \tag{7}$$

$$\sum_{k=1}^{q} w_k = 1, \quad w_j \geq 0 \tag{8}$$

$$x_i \geq 0, \quad i = 1,...,n \tag{9}$$

Where λ = ratio of the achievement level of objective functions

$\mu_{zk}(x)$ = the linear membership function *k*

w_k = weight of membership function *k*

k = index of objective functions

q = number of membership functions

x_i = decision variables

i = index of number of decision variables

n = number of decision variables

Application

In step 7 of the methodology, the optimization of the multi-objective optimization model is applied to the case study of Thai rice exporter. The data collected from company include the cost aspect, environmental aspect, and service quality. Some data of cost aspect is shown in Table 2. Some of environmental impact is presented in Table 3. The service quality data is illustrated in Table 4.

Table 2: Cost data inputted into the model

Cost items	Cost values
1. Amount of rice to transport per day	240 ton
2. Truck capacity	35 ton
3. Truck price	4,500,000 baht
4. Driver salary per year	216,000 baht
5. Maintenance per year	1,500,000 baht
6. Other cost per year	185,200 baht

Table 3: Environmental impact data inputted into the model

Environmental items	Environmental values
1. Truck acquisition	565.5 point
2. Truck manufacturing	133.1 point
3. Truck distribution	3.1 point
4. Truck energy use	5,283.6 point
5. Truck maintenance	2.2 point

Table 4: The probability of transportation time

Transportation time	probability
1 day	10%
2 days	20%
3 days	30%
4 days	30%
5 days	10%

Thus, the service quality can be described in the mathematical form as Equation 10.

$$Max\ \ S = \begin{pmatrix} 0.0, & n < 7 \\ 0.1, & n \geq 7 \\ 0.3, & n \geq 14 \\ 0.6, & n \geq 21 \\ 0.9, & n \geq 28 \\ 1.0, & n \geq 35 \end{pmatrix} \tag{10}$$

After the model is applied based on collected data, the results are presented in Table 5. Sample scenarios are illustrated to provide weights of three aspects which are cost, environmental, and service quality. The results show the optimal number of truck in fleet depends vastly on data and weights. It can be seen that the fleet size ranges from 7 to 35 trucks. In some cases, the cost and environmental impact is considerably weighed, the fleet size is quite small of 7 trucks. The scenario 3 shows the example of this situation which weights of cost, environmental, and service quality are 0.5, 0.5, and 0 respectively. However, as the service quality is highly prioritised, the number of truck increases significantly. The scenario 7 is the example for this situation. Their weights which are 0.1, 0.1, and 0.8 respectively provide the fleet size of 35 trucks.

Table 5: The best and worst value for each type of objective function

Scenarios	Cost	Environmental	Service Quality	Fleet size
1	0.33	0.33	0.33	**7**
2	0.50	0.00	0.50	**28**
3	0.50	0.50	0.00	**7**
4	0.00	0.50	0.50	**28**
5	0.80	0.10	0.10	**7**
6	0.10	0.80	0.10	**7**
7	0.10	0.10	0.80	**35**
8	0.70	0.15	0.15	**7**
9	0.15	0.70	0.15	**7**
Scenarios	Cost	Environmental	Service Quality	Fleet size
10	0.26	0.26	0.49	**21**
11	0.29	0.29	0.43	**14**
12	0.15	0.15	0.70	**28**
13	0.60	0.20	0.20	**7**
14	0.20	0.60	0.20	**7**
15	0.20	0.20	0.60	**28**
16	0.50	0.25	0.25	**7**
17	0.25	0.50	0.25	**7**
18	0.25	0.25	0.50	**28**
19	0.20	0.20	0.40	**28**
20	0.28	0.28	0.45	**14**

In step 8 of methodology, the decision maker selects the best scenario based on preference. The fleet size is provided as the chosen scenario.

Conclusion

This research provides a decision support tool for company to own truck fleet. This tool is developed based on the optimization model which includes three aspects of 1) cost, 2) environmental impact, and 3) service quality. The significant decision variable is the number of truck in fleet. The max-min membership function is developed to integrate three objectives simultaneously and generate the result of fleet size. Based on the data collected, it can be seen that the fleet size is mainly generated from the information of cost and environmental impact. In addition, the value of fleet size depends on time uncertainty of unloading rice at seaport. The more time which truck spending at seaport, the more trucks are required to cover all service demand.

In future work, the continuous data of service quality should be considered. This can provide the diversity of results in fleet size. In addition, the choice of energy consumption like natural gas or biodiesel may be considered to reduce total life cycle cost and environmental impacts.

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