EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Green point-to-point logistics at Kalasin: A case study of rice transportation

Arjaree Saengsathien and Krissada Namchimplee*

Department of Logistics Engineering and Transportation Technology, Faculty of Engineering and Industrial Technology, Kalasin University, Kalasin 46000, Thailand

Received 14 October 2022
Revised 3 December 2022
Accepted 15 December 2022

Abstract

More than half of Thailand's rice plantations are located in Kalasin due to its year-round access to irrigation systems that draw from Lam Pao Dam. The process of rice distribution significantly affects supply chain costs and atmospheric emissions. Generally, transportation decisions are based on truck drivers' experiences which can impact the efficiency of transport. As a result, this study aims to examine the effect that adopting green logistics practices has on the planning of delivery routes that help reduce transportation costs and protect the environment. This study provides a case analysis of rice transportation between a local mill in Kalasin and six main retailers to compare current practices by means of two-step problem solving. Following the mathematical model, the routing problem is solved using Excel Solver by considering truck capacity and customer demand. Afterwards, the scheduling problem is solved using an Excel spreadsheet by considering truck loads and distance between points. When transport routes were determined, the mill reduced fuel costs by 10.54% per delivery cycle, and when the schedule of delivery was established, the mill reduced greenhouse gas emissions by 24.77% per cycle. The reduction in distance travelled and level of pollution indicates that implementing green practices in logistics management is beneficial. This study identifies the need to consider the quantity of load between points on a trip to measure and lower environmental impacts. For road transport, Kalasin province can increase its reputation and be more competitive in the market if rice mills apply information technology to determine which delivery routes contribute to lower total costs and which delivery schedules contribute to lowering emissions.

Keywords: Rice, Green supply chain, Green logistics, Kalasin, Transportation

1. Introduction

Rice is the most important economic crop for Thailand. The northeastern region, including Kalasin province, is the country's largest rice production area. However, weaknesses in production, labour shortages, elderly farmers, price competition with competing countries in the Association of Southeast Asian Nations (ASEAN) such as Vietnam [1] and Cambodia, and emerging rival countries such as India and Myanmar impact the industry in Thailand. A study of logistics and rice supply chains will increase knowledge and awareness of problems and obstacles so that one can find solutions and improve efficiency in responding to the needs of customers at a lower cost.

The food supply chain contributes 26% of the total greenhouse gas (GHG) emissions in the world [2]. For Thailand, approximately 15% of the total emissions comes from the agricultural sector [3]. With the current climate change situation, this data signals the necessity to transform food systems in an effort to reduce GHGs which contribute to the ever-growing threat of global warming. The implementation of green logistics is becoming more popular because it can be applied in activities throughout the supply chain. Green logistics can reduce costs, create more value, save energy, and save the environment altogether in one single project.

Most stakeholders involved in the Kalasin rice supply chain, including community enterprises, cooperatives, mills, and small entrepreneurs, found that the logistics of rice production and transportation still face many environmental problems. The problems lie especially with non-intelligent transportation systems, the lack of standardised planning that causes empty backhaul, inappropriate routing, the use of diesel fuel in transport trucks that causes the emission of carbon dioxide (CO_2), dust and waste, the use of inappropriate packaging types and materials that causes transportation gaps and results in loss during transportation, and the inefficient use of resources that wastes raw materials, water, electricity, fuel, paper, etc. What is desperately needed is a more streamlined transport system to carry a product from its source to the customer.

Research and development on logistics systems that can protect and preserve the Thai environment are given a high level of importance. The government came up with the idea of designating Kalasin province as a special economic zone for rice production and related industries. The distribution of goods in Kalasin can be enhanced by using the double-track railway via the Jira junction and the highway route known as the East-West corridor to achieve systematic cost reduction. Therefore, this research uses concepts of management to analyse point-to-point logistics systems in Kalasin from the perspective of environmental sustainability. The practical research process was carried out to find suitable and environmentally friendly delivery routes.

*Corresponding author. Tel.: +6694 262 8338
Email address: krissada.na@ksu.ac.th
doi: 10.14456/easr.2022.75

2. Theory and literature review

2.1 Carbon footprint

A GHG is a gas that absorbs and emits radiant energy within the thermal infrared range. GHGs cause the greenhouse effect and contribute to climate change. The primary GHGs in the Earth's atmosphere are water vapour, CO_2, methane, nitrous oxide, and ozone [4]. GHG emissions may come from fossil fuel–powered vehicles that deplete dwindling oil reserves and impact air quality [5].

The lifecycle of GHGs are tracked through carbon foot printing. In Thailand, only 664 manufacturers have been granted carbon foot printing labels since 2009 (mostly in the food and beverage industry) and 70.78% of manufacturers decided not to continue the carbon foot printing programme after their labels expired [6]. The main reasons for implementing this initiative include green image enhancement, cost reduction, and employee development and satisfaction. However, a lack of social awareness of the label and climate change issues were the most significant challenges faced.

The development of green logistics can be considered from the perspective of green transportation where the consumption of fossil fuels is the main source of environmental pollution caused by logistics activities [7]. The amount of GHG emissions in the travel and transportation sector can be measured by using two approaches. The first approach is to use fixed emission or environmental impact factors per distance unit and/or per weight unit, per product, per vehicle that can be obtained from other environmental studies. The emissions can be calculated as GHG Emission ($kgCO_2e$) = Truck Load (t) × Distance (km) × Emission Factor ($kgCO_2e/tkm$). The second approach is to indirectly estimate the emission. The total energy consumed from transportation operations is calculated while the parameters such as distance, speed, or weight are considered [8].

2.2 Green logistics

Both businesses and policymakers should follow an integrated approach to measure the sustainability level of supply chains in three dimensions: the environment (e.g., process-related preventions, product-related optimisations, use of resources), the society (e.g., customer and manufacturer's ethical issues, supplier's cooperation and rights, employee aspects and employment systems, employee's compensations), and the economy (e.g., supply chain effectiveness, freight procurement and collaborative transportation management, revenue–cost balances and efficiency) [9]. In the environmental dimension of sustainable development, energy demand and CO_2 emissions are among the most frequently mentioned topics [10].

Logistics involves various activities (e.g., transportation system, distribution system, supply/demand planning, inventory management, production planning, etc.) relating to the movement of goods, services, and related information in a supply chain [11]. Transportation logistics is the process of obtaining, handling, and distributing goods from the point of origin to the point of consumption with the help of transportation. A point-to-point or direct transportation network involves shipments that go directly from the supplier to the buyer's location.

The transportation sector contributes significantly to environmental problems [12] and accounts for over 14% of CO_2 emissions at a global level [13]. The factors that affect GHG emissions from road transport include modal split, handling factor, average length of haul, loading factor, empty running, fuel efficiency, and carbon intensity [14]. These factors are influenced by logistics decisions, product characteristics, and various external factors. The logistics performance index (LPI) can be used along with environmental factors such as CO_2 emissions to describe the status of green logistics development at a national level [15].

There are three different sets of measures for reducing CO_2 in logistics operations, specifically transportation: the technological measure (e.g., transport fuels, vehicle efficiency, and vehicle technology), the regulatory and socio-economic measure (e.g., transport efficiency, traffic infrastructure management, integration of transport systems, economic aspects of change, broader environmental impacts, equity and accessibility, information and awareness, and infrastructure), and the safety and security measure (e.g., pricing, taxation, and regulation) [16]. In China, the air law revision details regulations for constraining GHGs and atmospheric pollutants, specifically particulate matter induced by industrial production, motor vehicles, motor vessels etc. Following this, the sustainability analysis of supply chain management through the prediction of particulate matter emissions shows that the steady growth of supply chain operations is accompanied by decreasing air pollutant emissions or a win–win situation for all parties involved [17].

Therefore, decision making at strategic, management, and operational levels in the food supply chain has undergone a review and is beginning to focus on environmental sustainability. From previous studies, problems can be categorised into five types based on the consideration of environmental issues namely energy, carbon emissions, CO_2 equivalent, waste, and quality assurance [18]. Moreover, various environmental sustainability integrated quantitative models have been used to provide alternative solutions for the problems that include life cycle assessment (LCA), decision support system (DSS), exact algorithm, analytical model, simulation, heuristics, etc.

Several studies related to transportation decisions that increase sustainability, for example, a study of time-dependent pollution routing problems that considers emissions in the cost function [19]; a study of mixed and simultaneous pickup and delivery, time windows, and road type–based routing problems that considers fuel consumption rate in relation to vehicle load fluctuation and varying travel time [20]; a study of time-constrained, multiple-stop, truck-routing problems that considers fuel consumption with a heavy payload [21]; a study of stochastic vehicle routing problems that considers CO_2 emissions under different weight and velocity [22]; a study of GIS-based route optimisation that considers CO_2 emissions [23-26]; a study of inventory routing problems for perishable products that considers the number of vehicle accidents and expired products in a bi-objective mathematical model [27]; and a study of multiple depot utilisation that considers CO_2 emissions [28].

Green logistics for freight transportation can be achieved by monitoring how vehicles are used in terms of both payload and empty running [29]. Potential factors for the adoption of green logistics practices in the freight transportation industry in Thailand include firm size, financial status, area of service, customer pressure, and support from the organisation [30]. From the literature review, strategies for the development of green logistics in Thailand include the management of transportation, storage, packaging, loading, and unloading; the development of green warehousing; the evaluation of logistics operation systems; the use of publicity, promotion, training and integrated information technology to increase awareness of green logistics; reverse logistics; and organizational and stakeholder pressure [31]. However, only a few studies on green logistics in Thailand were found in the literature. There has been no study on the green rice logistics system in Kalasin yet. This research aims to investigate green practices in the transportation of rice. As rice is an important economic crop for Thai people, the knowledge gained from this research can be used to manage rice logistics in the future.

3. Methods

The shortest and fastest delivery route is necessary for the development of green point-to-point logistics system for rice transportation towards increasing efficiency, reducing cost, and mitigating environmental impact.

The planning of delivery routes can be done using mathematical model and Microsoft Excel. An analysis on the management of rice transportation between Kalasin local rice mill and six main retailers can be done by means of two-step problem solving.

In the first step, a routing problem is solved. Following the mathematical model, customers are assigned to an appropriate route using Excel Solver under constraints of truck capacity and customer demand. To minimize the total transportation cost, fuel cost resulting from increasing travelling distance must be reduced. Afterwards, a scheduling problem is solved. Delivery stops in each route are scheduled using excel spreadsheet concerning emissions ($kgCO_2e$) that vary according to truck load and distance between points.

In the first step, a mathematical model can be developed for routing problems as follows:

Indices

i, j, k Indices of all customers (i = 1, 2, …, n), (j = 1, 2, …, m) and (k = 1, 2, …, l)

Parameters

a Transportation cost (Baht/Km.)

b 6-wheeler truck capacity (Ton/Trip)

c_{ij} Distance between customer i and customer j (Km.)

d_i Distance between customer i and mill (Km.)

d_j Distance between customer j and mill (Km.)

e_i Demand at customer i (Sacks)

e_j Demand at customer j (Sacks)

Decision Variable

$$x_{ij} \quad \begin{cases} 1 \text{ if customers } i\ i \text{ and } j\ j \text{are on the same route} \\ \quad 0 \text{ otherwise} \end{cases}$$

Objective Function:

Minimizing

$$a\sum_{j=1}^{n}\sum_{i=1}^{n}(x_{ij}c_{ij}) + a\sum_{i=1}^{n}\left(d_i\sum_{j=1}^{n}x_{ij}\right) + a\sum_{j=1}^{n}\left(d_i\sum_{j=1}^{n}x_{ij}\right) \tag{1}$$

Constraints

$$\sum_{i=1}^{n}x_{ik} + \sum_{j=1}^{m}x_{kj} = 1 \rightarrow;\ \forall k \tag{2}$$

$$\sum_{i=1}^{n}(x_{ik}d_j) + d_k\sum_{i=1}^{n}x_{ik} + \sum_{j=1}^{n}(x_{kj}d_j) + d_k\sum_{j=1}^{n}x_{kj} \le b\left(\sum_{i=1}^{n}x_{ik} + \sum_{j=1}^{n}x_{kj}\right) \rightarrow; \forall k \tag{3}$$

$$x_{ij} \in \{0,1\} \tag{4}$$

The objective function (1) aims to minimize the total transportation cost. Equation (2) ensures the demand of customers are fulfilled. Equation (3) limits the maximum transport capacity. Equation (4) is the binary decision variable constraint.

4. Results

A local rice mill in Kalasin distributes rice sacks to the main customers in 5 provinces in the Northeast including Yasothon, Ubon Ratchathani, Srisaket, Amnaj Charoen and Roi Et by using an 11-ton 6-wheeler truck that travels at a speed of 60 km./hr. The existing delivery is done in three days (three routes) following the driver's experience each week. On the first day, customers in Muang District, Roi Et and Muang District, Srisaket are covered. On the second day, demand from Muang District, Yasothon and Muang District, Amnaj Charoen are satisfied. In the last route, demand from Kham Khuean Kaeo District, Yasothon and Muang District, Ubon Ratchathani are fulfilled. Data on weekly demand and travelling distance are shown in Table 1-2, respectively.

Table 1 Weekly demand

Customer	Weekly Demand (Sack)	Weight (50 kgs/ sack)	Route
Roi Et (R)	50	2,500	1
Yasothon (Y)	100	5,000	2
Kham Khuean Kaeo (K)	100	5,000	3
Amnaj Charoen (A)	80	4,000	2
Ubon Ratchathani (U)	100	5,000	3
Srisaket (S)	100	5,000	1
Total Weight	26,500		
Total Customer	6		

Table 2 Distance between points (Km.)

Route	Mill	R	Y	K	A	U	S
R	89.5	0					
Y	118	67.8	0				
K	151	101	33.5	0			
A	165	123	56.1	63.3	0		
U	222	171	103	78.4	77	0	
S	281	223	163	139	161	80.5	0

4.1 Route planning

To solve the routing problem using Excel Solver, data on travelling distance between customers is shown in Table 3. The cost for transporting rice by using a 6-wheeler truck is 7 bath/km. The new proposed route is a trip to Muang District, Roi Et and Muang District, Yasothon. The second trip includes Kham Khuean Kaeo District, Yasothon and Muang District, Amnaj Charoen. The last trip involves Muang District, Srisaket and Muang District, Ubon Ratchathani as shown in Table 4 and Figure 1 shows a route comparison.

Table 3 Distance between customer i to customer j (Km.)

Route	R	Y	K	A	U	S
R	M	67.8	101	123	171	223
Y	M	M	33.5	56.1	103	163
K	M	M	M	63.3	78.4	139
A	M	M	M	M	77	161
U	M	M	M	M	M	80.5
S	M	M	M	M	M	M

Table 4 Route comparison

Customer	Old Route	New Route
Roi Et (R)	1	1
Yasothon (Y)	2	1
Kham Khuean Kaeo (K)	3	2
Amnaj Charoen (A)	2	2
Ubon Ratchathani (U)	3	3
Srisaket (S)	1	3
Total distance	1,384	1,238.1

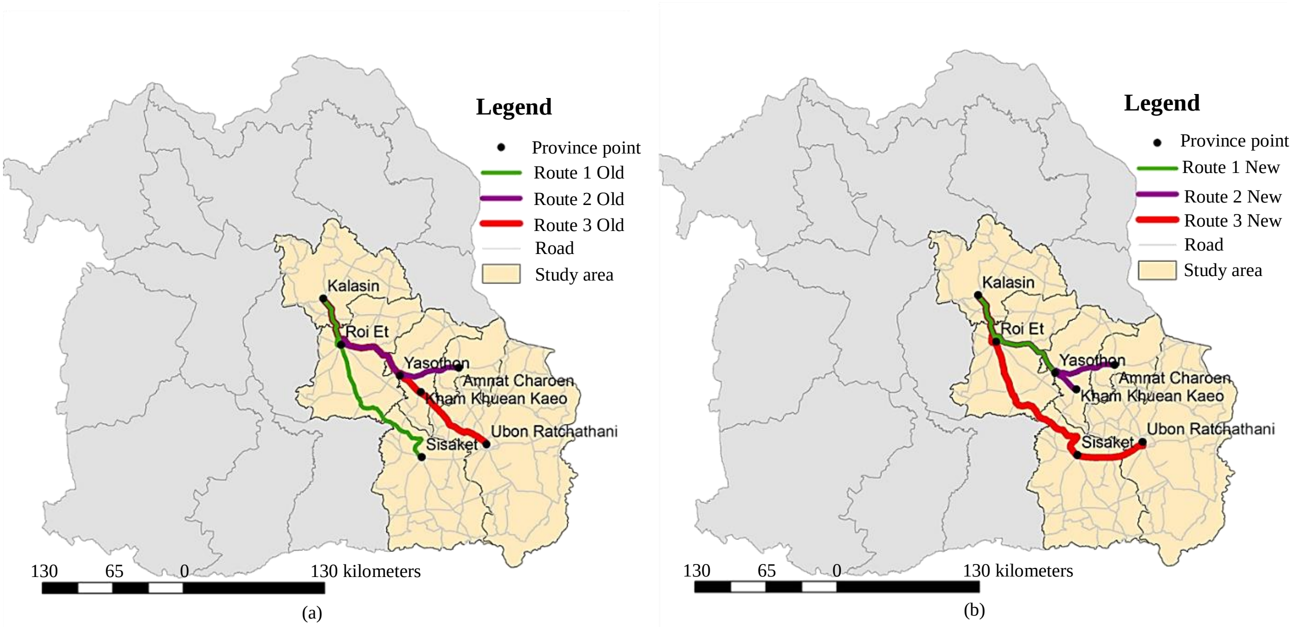

Figure 1 Route comparison: (a) old route and (b) new route.

For comparison, the result shows the value of the total cost, travel time at a truck speed of 60 km/h and the load on each route. As shown in Table 5, the total distance, the maximum travel time, and the minimum travel time of the new route are lower than the original route. In addition to savings on transportation costs, it also has a positive effect on drivers and truck operating conditions.

Table 5 Comparisons of travelling distance, time, and truck load

Route		1	2	3	Total
Distance (km.)	Old	593.5	339.1	451.4	1,384
Distance (km.)	New	275.3	379.3	583.5	1,238.1
% Difference		53.61	-11.85	-29.26	10.54
Cost (THB)	Old	4,154.5	2,373.7	3,159.8	9,688
Cost (THB)	New	1,927.1	2,655.1	4,084.5	8,666.7
% Difference		53.61	-11.85	-29.26	10.54
Travelling Time (hr.)	Old	9.89	5.65	7.52	23.07
Travelling Time (hr.)	New	4.59	6.32	9.73	20.64
% Difference		53.61	-11.85	-29.26	10.54
Truck Load (Tons)	Old	7.5	9	10	26.5
Truck Load (Tons)	New	7.5	9	10	26.5

4.2 Delivery scheduling

In this simulation of the solution of green point-to-point logistics management, the method used to measure the amount of GHG emissions from transportation activity is the fixed emission method or environmental impact factors method per unit distance per vehicle. In the second step, the following situations can be simulated for the delivery scheduling by using Spreadsheets simulation. The three proposed route arrangements can be classified into 6 cases of delivery schedule as shown in Table 6.

The calculation of the GHG emission coefficients from transportation by interpolating factors from Table 7 is shown in Table 8.

The solution of the delivery scheduling problem using spreadsheets simulation method is shown in Table 9. The appropriate schedules of each route are as follows; Case 1 from Mueang District, Roi Et to Muang District, Yasothon is selected with the amount of emissions at 200.85 kgCO_2e, Case 3 from Kham Khuean Kaeo District, Yasothon to Mueang District, Amnat Charoen is selected with the amount of emissions at 274.62 kgCO_2e and Case 5 from Muang district, Ubon Ratchathani to Muang District, Sisaket is selected with the amount of emissions at 418.52 kgCO_2e.

Table 6 Scheduling alternatives

	Route 1		Route 2		Route 3	
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Customer	Mill-> R->Y-> Mill	Mill-> Y->R-> Mill	Mill-> K->A-> Mill	Mill-> A->K-> Mill	Mill-> U->S-> Mill	Mill-> S->U-> Mill
Distance (km.)	89.5-> 67.8-> 118	118-> 67.8-> 89.5	151-> 63.3-> 165	165-> 63.3-> 151	222-> 80.5-> 281	281-> 80.5-> 222
Truck Load (Tons)	7.5-> 5-> 0	7.5-> 2.5-> 0	9-> 5-> 0	9-> 4-> 0	10-> 5-> 0	10-> 5-> 0
Loading Efficiency (%)	68.2-> 45.5-> 0	68.2-> 22.7-> 0	81.8-> 45.5-> 0	81.8-> 36.4-> 0	90.9-> 45.5-> 0	90.9-> 45.5-> 0

Table 7 Greenhouse gas emission coefficient

Name	Unit	Emission Factor ($kgCO_2$ eq/unit)
Large 6-wheeler pickup truck with 11-ton sturdy drive not loaded 0% Loading	km	0.6032
Large 6-wheeler pickup truck with 11-ton sturdy drive half loaded 50% Loading	tkm	0.1335
Large 6-wheeler pickup truck with 11-ton sturdy drive heavily loaded 75% Loading	tkm	0.0935
Large 6-wheeler pickup truck with 11-ton sturdy drive fully loaded 100% Loading	tkm	0.0728

Table 8 Greenhouse gas emission coefficient for each case

Customer	Loading Efficiency (%)	Greenhouse Gas Emission Coefficient (kgCO_2e/unit)
Case 1	68.2->45.5->0	0.1044->0.1758->0.6032
Case 2	68.2->22.7->0	0.1044->0.3900->0.6032
Case 3	81.8->45.5->0	0.0879->0.1758->0.6032
Case 4	81.8->36.4->0	0.0879->0.2613->0.6032
Case 5	90.9->45.5->0	0.0803->0.1758->0.6032
Case 6	90.9->45.5->0	0.0803->0.1758->0.6032

Table 9 Greenhouse gas emission for each case

Case	1	2	3	4	5	6
Forward						
Truck Load (t)	7.5	7.5	9	9	10	10
Distance (km.)	89.5	118	151	165	222	281
Emission Factor (kgCO_2e/tkm)	0.1044	0.1044	0.0879	0.0879	0.0803	0.0803
GHG Emission (kgCO_2e)	70.0785	92.394	119.4561	130.5315	178.266	225.643
Connection						
Truck Load (t)	5	2.5	5	4	5	5
Distance (km.)	67.8	67.8	63.3	63.3	80.5	80.5
Emission Factor (kgCO_2e/tkm)	0.1758	0.3900	0.1758	0.2613	0.1758	0.1758
GHG Emission (kgCO_2e)	59.5962	66.1050	55.6407	66.1612	70.7595	70.7595
Backhaul						
Distance (km.)	118	89.5	165	151	281	222
Emission Factor (kgCO_2e/tkm)	0.6032	0.6032	0.6032	0.6032	0.6032	0.6032
GHG Emission (kgCO_2e)	71.1776	53.9864	99.5280	91.0832	169.4992	133.9104
Total GHG Emission (kgCO_2e)	200.8523	212.4854	274.6248	287.7759	418.5247	430.3129

Table 10 Comparison of vehicle scheduling

Customer	Delivery Schedule		
	Green Case	Worst Case	Current Practice
Route 1	Case 1: Mill->R->Y->Mill	Case 2: Mill->Y->R->Mill	Mill->S->R->Mill
Route 2	Case 3: Mill->K->A->Mill	Case 4: Mill->A->K->Mill	Mill->A->Y->Mill
Route 3	Case 5: Mill->U->S->Mill	Case 6: Mill->S->U->Mill	Mill->U-> K->Mill
Greenhouse Gas Emission (kgCO_2e)	894.0018	930.5742	1,188.3636

For comparison, the result shows the relevant environmental impact of the proposed green delivery schedule, the worst-case delivery schedule and the delivery schedule of the current practice as shown in Table 10. If the goods are shipped in the green order, emissions can be reduced by up to 3.93% per delivery cycle, equivalent to 1,901.7648 kgCO_2e per year compared to worst case delivery schedule and 24.77% per delivery cycle, equivalent to a decrease in emissions of up to 15,306.81 kgCO_2e per year compared to the current delivery schedule of the mill (the former case).

5. Discussion and conclusions

A case study of rice transportation between mill and retail stores was quantitatively analysed using statistical and mathematical methods. The results showed that past deliveries from local mill to customers were made using the mill's own truck and logistics decisions were based solely on the driver's experience. There was no effective route planning. However, route allocation with an emphasis on the lowest total cost reduced fuel costs by up to 10.54% per delivery cycle, which is equivalent to savings of up to 53,107 baht per year. Furthermore, decreasing the driving distance benefits the environment through a reduction in fuel consumption. This result is in agreement with other findings that a reduction in driving distances through appropriate route planning can lessen environmental impacts and the operational costs of transportation [5, 22, 26, 32, 33]. As a result, planners should consider assigning customers to a route by paring the customers that have the greatest distance savings. Then, the delivery is prioritised so that the sum of distance, time, or total cost is the lowest, while the total weight of the truck does not exceed its capacity and is within the criteria prescribed by law.

The scheduling of shipments in each delivery route affects the environment to a different extent. A product lifecycle assessment method was used to improve the productivity and environmental efficiency of the process with a focus on the amount of GHG emissions from ongoing shipping activities. When the delivery schedule was determined by considering the transport distance, travel load, empty backhaul, and emission coefficient, GHG emissions were reduced by up to 3.93% per delivery cycle, which is equivalent to 1,902 kgCO_2e per year compared to the worst-case schedule and up to 24.77% per delivery cycle, which is equivalent to 15,307 kgCO_2e per year compared to the current practice. This result is in agreement with other findings that the weight (including both vehicle weight and loading weight) affects emissions given appropriate vehicle scheduling [21-23]. Therefore, if it is not possible to avoid driving an empty truck, drivers should consider running an empty backhaul on the shortest route possible.

Furthermore, designing a new schedule means a new delivery date. For a green practice, customers in Yasothon, Kham Khuean Kaeo, and Srisaket and customers in Ubon Ratchathani, Roi Et, and Amnaj Charoen may have different dates of shipment. In this case study, customers are willing to wait for goods as long as the delivery is done once a week. While the existing delivery is done in three days, the weekly schedule is flexible. After a change in schedule, the product may arrive faster or slower than usual within a maximum of three days. Thus, there is no significant effect on the inventory. However, in light of time window constraints, it may lead to a tighter schedule. In this case, the weekly delivery schedule has to be rearranged following the delivery requirements.

To conclude, the results of this study are limited to this specific problem. The results may vary due to different parameters including truck capacity, truck speed, spatially dissimilar forward and return paths, etc. Furthermore, the results of this study support the development of green logistics systems in Kalasin that are in line with the project "Esan Rice City: Kalasin Model" as follows:

1. Energy Conservation: As most rice products at Kalasin are transported by road, biodiesel and gasohol should be used. The route is planned with the lowest total cost in mind to reduce energy consumption and air pollution.

2. Effective Use of Resources: When communicating, planning, and storing information on purchases, production, storage, and transportation, information technology systems should be used as a medium instead of documents for accuracy and trackability.

3. Product Life Cycle Assessment: Following an assessment of the environmental impact per unit of product being transported, shipments should be scheduled to reduce emissions from full loads and empty backhauls for climate change mitigation and consumer visibility.

This study provides a tool to facilitate the planning of delivery routes and schedules. The findings contribute to tactical decision making for local rice mills who need to improve their performance by initiating green and cost-effective deliveries. The findings can also be used to help promote social awareness of carbon foot printing and climate change which can further enhance national sustainability. For future work, it would be more realistic to take the vehicle speed, road conditions, and traffic conditions into account. Road pavement affects GHG emissions from transportation as well and deserves further study.

6. Acknowledgements

This work was supported by the Coordinating Center for Thai Government Science and Technology Scholarship Students (CSTS) and National Science and Technology Development Agency (NSTDA).

7. References

[1] Hanaoka S, Nguyen LX, Nakamichi K, Chu VH. Clarification of the structure of rice supply chain and transport mode choice in Vietnam. J East Asia Soc Transp Studies. 2017;12:146-57.
[2] Steiner A, Aguilar G, Bomba K, Bonilla JP, Campbell A, Echeverria R, et al. Actions to transform food systems under climate change. Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); 2020.
[3] Gütschow J, Jeffery L, Gieseke R, Günther A, Gebel R, Stevens D, et al. The PRIMAP-hist national historical emissions time series (1850-2017). Potsdam: GFZ Data Services; 2019.
[4] The Greenhouse Gas Management Organization. Organization carbon footprint assessment. Bangkok: The Greenhouse Gas Management Organization; 2015. [In Thai]
[5] Johns Hopskins Center for Livable Future. Food system primer [Internet]. 2016 [cited 2022 Oct 10]. Available from: http://www.foodsystemprimer.org/food-distribution/.
[6] Sureeyatanapas P, Yodprang K, Varabuntoonvit V. Drivers, barriers and benefits of product carbon footprinting: a state-of-the-art survey of Thai manufacturers. Sustainability. 2021;13(12):6543.
[7] McKinnon A. Green logistics: the carbon agenda. Log Forum. 2010;6(3):1-9.
[8] Soysal M, Bloemhof-Ruwaard JM, van der Vorst JGAJ. Modelling food logistics networks with emission considerations: the case of an international beef supply chain. Int J Prod Econ. 2014;152:57-70.
[9] Hendiani S, Liao H, Jabbour CJC. A new sustainability indicator for supply chains: theoretical and practical contribution towards sustainable operations. Int J Logist Res.Appl. 2020;25:384-409.
[10] Seuring S. A review of modeling approaches for sustainable supply chain management. Decis Support Syst. 2013;54:1513-20.
[11] Sarder MD. Logistics transportation systems. Amsterdam: Elsevier; 2020.
[12] Aronsson H, Huge Brodin M. The environmental impact of changing logistics structures. Int J Logist Manag. 2016;17(3):394-415.
[13] Stern N. Stern Review: The economics of climate change. Cambridge: Cambridge University Press. 2006.
[14] Piecyk MI, Mckinnon AC. Forecasting the carbon footprint of road freight transport in 2020. Int J Prod Econ. 2010;128(1):31-42.
[15] Lu M, Xie R, Chen P, Zou Y, Tang J. Green transportation and logistics performance: an improved composite index. Sustainability. 2019;11(10):2976.
[16] Antoni A, Perić M, Čišić D. Green logistics-measures for reducing CO_2. Pomorstvo Sci J Marit Res. 2015;29(1):45-51.
[17] Qian Y, Li Z, Tan R. Sustainability analysis of supply chain via particulate matter emissions prediction in China. Int J Logist Res Appl. 2021;25(4-5):591-604.
[18] Saengsathien A. Modelling and determining inventory decisions for improved sustainability in perishable food supply chains [thesis]. Exeter: University of Exeter; 2015.
[19] Franceschetti A, Honhon D, Van Woensel T, Bektaş T, Laporte G. The time-dependent pollution-routing problem. Transp Res B: Methodol. 2013;56:265-93.
[20] Srijaroon N, Sethanan K, Jamrus T, Chien CF. Green vehicle routing problem with mixed and simultaneous pickup and delivery, time windows and road types using self-adaptive learning particle swarm optimization. Eng Appl Sci Res. 2021;48(5):657-69.
[21] Suzuki Y. A new truck-routing approach for reducing fuel consumption and pollutants emission. Transp Res D: Transp Environ. 2011;16(1):73-7.
[22] Khamsuk K. Determination of stochastic vehicle routing for reducing carbon dioxide emission [dissertation]. Chiang Mai: Chiang Mai University; 2014.
[23] Bosona T, Nordmark I, Gebresenbet G, Ljungberg D. GIS-based analysis of integrated food distribution network in local food supply chain. Int J Bus Manag. 2013;8(17):13-34.
[24] Abousaeidi M, Fauzi R, Muhamad R. Geographic Information System (GIS) modeling approach to determine the fastest delivery routes. Saudi J Biol Sci. 2016;23(5):555-64.
[25] Schröder M, Cabral P. Eco-friendly 3D-routing: a GIS based 3D-routing-model to estimate and reduce CO_2-emissions of distribution transports. Comput Environ Urban Syst. 2019;73:40-55.
[26] Yachai K, Kongboon R, Gheewala SH, Sampattagul S. Carbon footprint adaptation on green supply chain and logistics of papaya in Yasothon Province using geographic information system. J Clean Prod. 2021;281:125214.
[27] Rahimi M, Baboli A, Rekik Y. Sustainable inventory routing problem for perishable products by considering reverse logistic. IFAC-Papersonline. 2016;49(12):949-54.
[28] Wang S, Han C, Yu Y, Huang M, Sun W, Kaku I. Reducing carbon emissions for the vehicle routing problem by utilizing multiple depots. Sustainability. 2022;14(3):1264.

[29] Shah KJ, Pan SY, Lee I, Kim H, You Z, Zheng JM, et al. Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies. J Clean Prod. 2021;326:129392.
[30] Sureeyatanapas P, Poophiukhok P, Pathumnakul S. Green initiatives for logistics service providers: An investigation of antecedent factors and the contributions to corporate goals. J Clean Prod. 2018;191:1-14.
[31] Aroonsrimorakot S, Laiphrakpam M, Mungkun S. Green Logistics (GL) for Environmental Sustainability: A Review in Search of Strategies for Thailand's GL Management. ABAC J. 2022;42(2):293-319.
[32] Bosona T, Gebresenbet G, Nordmark I, Ljungberg D. Integrated logistics network for the supply chain of locally produced food, Part I: Location and route optimization analyses. J Serv Sci Manag. 2011;4(2):174-83.
[33] McKinnon A, Browne M, Whiteing A, Piecyk M. Green logistics: Improving the environmental sustainability of logistics. 3rd ed. Philadelphia: Kogan Page Publishers; 2015.