

A System Dynamics Model of Multimodal Transportation of Rubber Products in Thailand



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Abstract Thailand is the world's leading natural rubber exporting country, accounting for 36.8% of the world market. In addition, the country is a member of the ASEAN Economic Community, aiming to be the center of the transportation in the region. Multimodal transportation is then encouraged to enhance the transport efficiency and reduce the logistics cost. This study develops the system dynamics model of multimodal transportation of rubber product in Thailand, utilizing the system dynamics modeling approach. Six savings and five costs related to the multimodal transportation are considered in the model. The simulation results show a negative cash flow at the beginning of the simulation years due to high investment in the multimodal-related facilities and infrastructure. With continuous use of multimodal transportation, the net cash flow becomes positive, and the project reaches the internal rate of return of 12% at the end of year 13. The results also show that the saving in truck rental cost and the product damage cost are the most important benefit and cost of multimodal transportation, respectively. The study results can be used as a guideline for the rubber and exporting companies, as well as the government, to effectively plan for the multimodal transportation in the long-term.

Keywords Multimodal transportation · Rubber · System dynamics modeling · Thailand

1 Introduction

Thai economy is growing, specifically in the exporting area that rises to 9.7% in 2017 (Workman 2019). After joining the ASEAN Economic Community (AEC), Thailand gains the benefits of tax reduction within the AEC countries, bringing even more export products to the market (NESDB 2015). Main export products include

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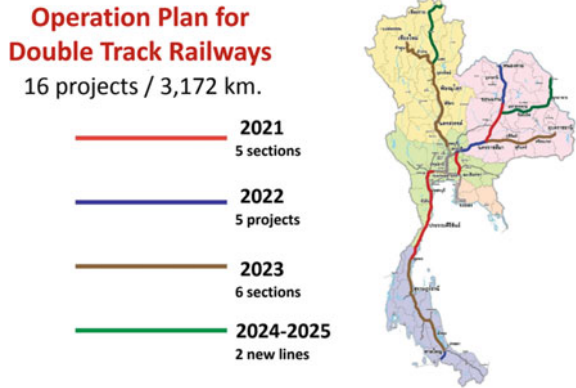
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Fig. 1 Double track system project (Thongkamkoon 2017)



automobiles, electronic devices, rubber, rice, and cassava. Currently, Thailand is the world’s largest producer and exporter of rubber products, accounting for 36.8% of the world market. The southern part of Thailand is the largest latex plantations area, accounting for over 70% of the country’s supply. Major partner countries are China, United States of America, and Malaysia with 26.7%, 11.7%, and 9.3% of the total imported amount, respectively (Workman 2019).

Thailand aims to be the center for logistics and transportation in the AEC countries. Motor mode is the major mode of transportation in Thailand. It is, however, the most expensive mode among the three modes, with an average logistics cost of two to three times higher (Wongsanguan 2018). The government, therefore, initiates a number of projects to encourage the use of multimodal transportation to reduce logistics and transportation cost. This includes the double track system project throughout the country to promote social stability, augment economic stability, promote transport security and safety, and boost competitiveness (Thongkamkoon 2017). Sixteen sub-projects are planned with around 15,000 million dollars budget (see Fig. 1). It is expected that the double track system project, more of multimodal transportation will be initiated, thus reducing logistics cost in the long-term.

To enhance the transportation effectiveness and reduce logistics cost, this study aims to examine savings and costs of multimodal transportation of rubber product utilizing a system dynamics modelling approach. It is expected that the study results will provide a guidance to the rubber and transportation industries to effectively plan for rubber transportation in the long-term.

2 Multimodal Transportation of Rubber Product

Multimodal transportation is the coordinated use of two or more modes of movement in transferring goods. It can be a combination of truck, rail, air, or ship modes. It provides convenient and economical connections of various modes to make complete

journey from origin to destination. Several studies have been conducted in the area of multimodal transportation of rubber product in Thailand. Santha (2015), for example, examined the transition from single-mode to multimodal transportation of rubber in the southern part of Thailand using multimodal regression method. The results show that multimodal transportation minimizes time loss at transshipment points, provides faster transit of goods, reduces burden of documentation and formalities, and saves cost. Luathep et al. (2016), similarly, studied the impact of transport infrastructure development on a modal shift for rubber product transport in the southern Thailand. The multimodal transport model was developed to evaluate the impact, and the results show that if all government projects, including the improvement and expansion of major roads to have at least four lanes along with the development of rail and water transports, are implemented, the transport time and cost could be reduced. BOI (2018) provided information regarding 10 trading and multimodal transportation centers, including Songkhla province, to aid the export of rubber and other products.

In this study, the multimodal transportation is considered in the rubber product transportation using the combination of truck and train modes. The origin of the study is at the major rubber export company located in Songkhla province (the southern part of Thailand), and the destination is at Laemchabang port, which is the major export port of Thailand located in the eastern part of Thailand. The products are to be delivered using the truck mode from the origin to Thung Pho railway station, where the container yard (CY) is provided for temporary storage. They are then transferred to the trains to continue their journey to Laemchabang port for the final exporting process.

3 System Dynamics Model of Multimodal Transportation of Rubber Product

System dynamics (SD) modelling approach is used to examine multimodal transportation of rubber product in Thailand in the long-term. It has been applied in many studies. Lewe et al. (2014), for example, developed a system dynamics model for multimodal intercity transportation that integrates socioeconomic factors, mode performance, aggregated demand and capacity. Perez-Lespier (2013), on the other hand, developed an SD model to identify and understand major elements and disruptions that, altogether, affect the efficiency of the multimodal transportation system in USA.

In this study, the SD modelling is utilized to develop the SD model of multimodal transportation of rubber products in Thailand. Various literatures have been conducted to extract key savings and costs of multimodal transportation. Rinsatitnon et al. (2018), for example, mentioned that by using multimodal transportation, the company can save fuel cost. Transport Corporation of India Limited (2018) added that by using multimodal transportation, accidents can be reduced, leading to less accident cost. Muangneua (2013), in contrast, stated that multimodal transportation requires a longer transit time than that for road transportation. Kruse et al. (2017)

Table 1 Data for the SD model of multimodal transportation of rubber product

Benefit and cost	Data
Saving in accident cost	• Accident cost = 20,715.20 baht/accident
Saving in reimbursement cost	• Chances of getting accidents: minor = 96.69% major = 3.31% • Reimbursement cost: minor = 80,000 baht/accident major = 300,000 baht/accident
Saving in truck driver cost	• Truck driver cost = 216,000 baht/person/year
Saving in fuel cost	• Diesel price = 30 baht/L • Fuel consumption rate for truck = 3.50 km/L • Fuel consumption rate for train = 0.12 km/L • Capacity: truck = 20 tons/truck train = 2000 tons/train
Saving in truck rental cost	• Truck rental cost = 3.65 million baht/truck/year
Saving in carbon dioxide tax	• Carbon dioxide tax = 500 baht/ton-CO ₂ • CO ₂ emission rate: truck = 107.37 g-CO ₂ /ton-km train = 13.37 g-CO ₂ /ton-km
Product return cost	• Train delay time = 0.75 h/round • Product return rate = 4.31%
Lift-on and lift-off cost	• Lift-on and lift-off cost = 850 baht/round
Tariff cost	• Tariff cost = 0.81 baht/km
Product damage cost	• Product damage chance = 2.37%

Note References include J&P Transport (2018), Road Accident Victims Protection Company Limited (2018), Transport Corporation of India Limited (2018), NESDB (2015), Kruse et al. (2017), Pornchai (2017), Protopapas et al. (2012), Wattanakuljarus (2012)

mentioned that the use of multimodal transportation requires lift on and lift off activities during transshipment processes.

A total of six savings and five costs are used for the development of SD model of multimodal transportation of rubber product in Thailand. Savings include (1) saving in accident cost, (2) saving in reimbursement cost, (3) saving in truck driver cost, (4) saving in fuel cost, (5) saving in truck rental cost, and (6) saving in carbon dioxide tax. Five costs, on the other hand, include (1) investment of the container yard, (2) product return cost, (3) lift-on and lift-off cost, (4) tariff cost, and (5) product damage cost. Both secondary and primary data used to develop equations for the SD model of multimodal transportation of rubber product are as shown in Table 1.

3.1 Saving in Accident Cost

According to the Transport Corporation of India Limited (2018), chances of getting road accidents can be reduced with the utilization of multimodal transportation, as it reduces the number of trucks in the transportation processes. According to the

Ministry of Road Transport and Highways (2016), the accident rate (AR) is averaged at 3.5 accidents/truck/year. Less trucks, then, tend to reduce the accident cost, which is averaged at 20,715.20 baht/accident. Equations 1–3 are used to calculate saving in accident cost, where SAC = saving in accident cost (baht/year), ACTT = accident cost of truck mode only (baht/year), ACTM = accident cost of multimode (baht/year), TT = trucks used in the truck mode only (trucks/year), TM = trucks used in the multimode (trucks/year), AR = accident rate (accidents/truck/year), and AC = accident cost (baht/accident).

$$SAC = ACTT - ACTM \tag{1}$$

$$ACTT = TT \times AR \times AC \tag{2}$$

$$ACTM = TM \times AR \times AC \tag{3}$$

3.2 Saving in Reimbursement Cost

A smaller number of accidents also leads to less reimbursement cost. In this study, the reimbursement cost is separated into minor and major cases, with chances of 96.69% and 3.31%, and the reimbursement cost of 80,000 and 300,000 baht per reimbursement, respectively, as shown in Table 1. Equations 4–6 are used to calculate saving in reimbursement cost, where SRC = saving in reimbursement cost (baht/year), SRCMN = saving in reimbursement cost based on minor cases (baht/year), SRCMJ = saving in reimbursement cost based on major cases (baht/year), MNC = chance of having minor cases (%), MNR = reimbursement cost of minor cases (baht/accident), MJC = chance of having major cases (%), and MJR = reimbursement cost of major cases (baht/accident) (Road Accident Victims Protection Company Limited 2018).

$$SRC = SRCMN + SRCMJ \tag{4}$$

$$SRCMN = (TT - TM) \times AR \times MNC \times MNR \tag{5}$$

$$SRCMJ = (TT - TM) \times AR \times MJC \times MJR \tag{6}$$

3.3 Saving in Truck Driver Cost

The use of multimodal transportation results in less trucks used. This implies less labors, especially truck drivers, used for transport, assuming one truck driver per one truck. Equation 7 is used to calculate saving in truck driver cost, where STD = saving in truck driver cost (baht/year) and TDC = truck driver cost (baht/truck/year).

$$\text{STD} = (\text{TT} - \text{TM}) \times \text{TDC} \quad (7)$$

3.4 Saving in Fuel Cost

With less trucks used, fuel cost can be saved. In this study, saving in fuel cost is calculated based on the average fuel price, fuel consumption rate, distance from the origin to the destination based on the transportation mode, hauling capacity, and number of transport rounds per year. Equations 8–10 are used to calculate the fuel cost savings, where SFC = saving in fuel cost (baht/year), FCTM = fuel cost based on the truck mode only (baht/year), FCMM = fuel cost based on the multimode (baht/year), DTM = distance traveled by truck mode only (i.e. from the rubber company to Laemchabang port) (km/round), RTM = number of rounds per year based on the truck mode only (rounds/year), FCTTM = fuel consumption rate based on the truck mode (km/L), FC = fuel cost (i.e. diesel price in this study) (baht/L), DTMCY = distance traveled by truck in the multimode (i.e. from the rubber company to Thung Pho railway station) (km/round), RTMCY = number of rounds per year of truck in the multimode (rounds/year), DRMLC = distance traveled by train in the multimode (i.e. from the Thung Pho railway station to Laemchabang port) (km/round), RRMLC = number of rounds per year of train in the multimode (rounds/year), and FCTRM = fuel consumption rate based on the train mode (km/L).

$$\text{SFC} = \text{FCTM} - \text{FCMM} \quad (8)$$

$$\text{FCTM} = (\text{DTM} \times \text{RTM}) / \text{FCTTM} \times \text{FC} \quad (9)$$

$$\begin{aligned} \text{FCMM} = & [(\text{DTMCY} \times \text{RTMCY}) / \text{FCTTM} \times \text{FC}] \\ & + [(\text{DRMLC} \times \text{RRMLC}) / \text{FCTRM} \times \text{FC}] \end{aligned} \quad (10)$$

3.5 Saving in Truck Rental Cost

In this study, it is assumed that there is no investment in trucks. As a result, all trucks used in the transportation are rented (J&P Transport 2018). With less trucks used in the multimodal transportation, truck rental cost is reduced. Equation 11 is used to calculate the saving in truck rental cost, where STR = saving in truck rental cost (baht/year) and TRC = truck rental cost (baht/truck/year).

$$STR = (TT - TM) \times TRC \quad (11)$$

3.6 Saving in Carbon Dioxide Tax

Saving in CO₂ tax is based on the emission rate of each truck mode, with the CO₂ tax of around 500 baht/ton-CO₂. Equations 12–14 are used to calculate saving in carbon dioxide tax, where SCT = saving in CO₂ tax (baht/year), CTTM = CO₂ tax based on the truck mode only (baht/year), CTMM = CO₂ tax based on the multimode (baht/year), TKMTM = total tons-kilometers of truck mode only per year (i.e. from the rubber company to Laemchabang port) (tons-kilometers/year), ERTM = emission rate of the truck mode (ton-CO₂/ton-kilometers), CT = CO₂ tax (baht/ton-CO₂), TKMTMCY = total tons-kilometers of truck in the multimode (i.e. from the rubber company to Thung Pho railway station) (tons-kilometers/year), TKMRMLC = total tons-kilometers of train in the multimode (i.e. from the Thung Pho railway station to Laemchabang port) (tons-kilometers/year), ERRM = emission rate of the train mode (ton-CO₂/tons-kilometers) (Wattanakuljarus 2012).

$$SCT = CTTM - CTMM \quad (12)$$

$$CTTM = TKMTM \times ERTM \times CT \quad (13)$$

$$CTMM = [(TKMTMCY \times ERTM) + (TKMRMLC \times ERRM)] \times CT \quad (14)$$

3.7 Investment in the Container Yard

To accommodate the multimodal transportation, the investment in the container yard is required at Thung Pho railway station. In this study, the investment cost of 50 million baht is incurred at the beginning of the simulation year.

3.8 Product Return Cost

The use of multimodal transportation may reduce the transportation cost, but increase delay, thus causing the product return cost. In this study, the delay of train mode is estimated at 0.75 h per round, and the product return rate is 4.31%. With the rubber price of 54,472 baht/ton, the product return cost can be calculated, with Eq. 15, where PRC = product return cost (baht/year), TDL = total delay hours per year (hours/year), PRR = product return rate (%), HPR = time used per round (hours/round), TPR = capacity transported per round (tons/round), and RBP = rubber price (baht/ton) (Office of the Rubber Replanting Aid Fund 2015).

$$\text{PRC} = (\text{TDL} \times \text{PRR}) / \text{HPR} \times \text{TPR} \times \text{RBP} \quad (15)$$

3.9 Lift-on and Lift-off Cost

The use of multimodal transportation requires the lift-on and lift-off processes. The lift-on and lift-off cost (LLC) is then based on the cost per round (LL) and the number of rounds per year (RRMLC) (see Eq. 16).

$$\text{LLC} = \text{LL} \times \text{RRMLC} \quad (16)$$

3.10 Tariff Cost

Tariff is paid when train mode is used. Tariff cost is calculated based on the tariff cost per kilometer (TF), distance from Thung Pho railway station to Laemchabang port (DRMLC), and number of rounds per year (RRMLC) (see Eq. 17).

$$\text{TFC} = \text{TF} \times \text{DRMLC} \times \text{RRMLC} \quad (17)$$

3.11 Product Damage Cost

The use of multimodal transportation may cause product damage during the transshipment processes. According to NESDB (2015), the rubber product has a product damage chance of 2.37%. The product damage cost is calculated with Eq. 18, where PDC = product damage cost (baht/year), TPY = total tons transported per year

(tons/year), and PDCH = product damage chance (%).

$$PDC = TPY \times PDCH \times RBP \tag{18}$$

4 Simulation Results

The SD model of multimodal transportation of rubber product is simulated, and the simulation results are as shown in Fig. 2. At the beginning of the simulation, the net cash flow is negative due to the investment in the container yard at Thung Pho railway station. After that, the savings of multimodal transportation start to increase, raising the net cash flow to be positive at the end of year 2.

Closer examination of savings and costs, as shown in Figs. 3 and 4, reveals that saving in truck rental cost and product damage cost are the most significant. This is consistent with MacAndrews (2019), who stated that the rise of truck costs and increase in regulation regarding drivers' hours shift the single transportation to multimodal transportation modes. Solistica (2018), on the other hand, mentioned that product damage, resulting from accidents and mishandling during storage, transport, and transshipment, represents not only financial loss, but also delays for the manufacturing or commercial operations of the company.

The internal rate of return (IRR) is further used to examine the feasibility of the project. According to Bonzanigo and Kalra (2014), the minimum acceptable IRR for

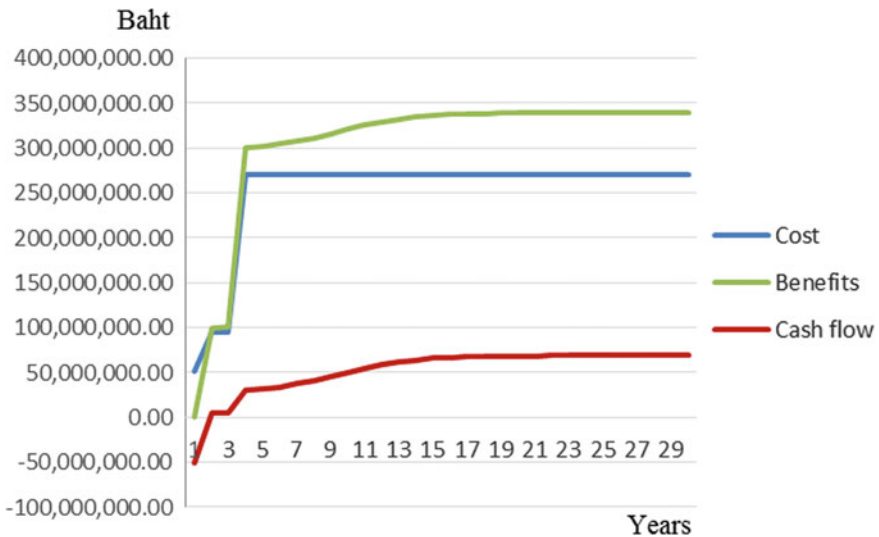


Fig. 2 Simulation results of savings, costs, and net cash flow

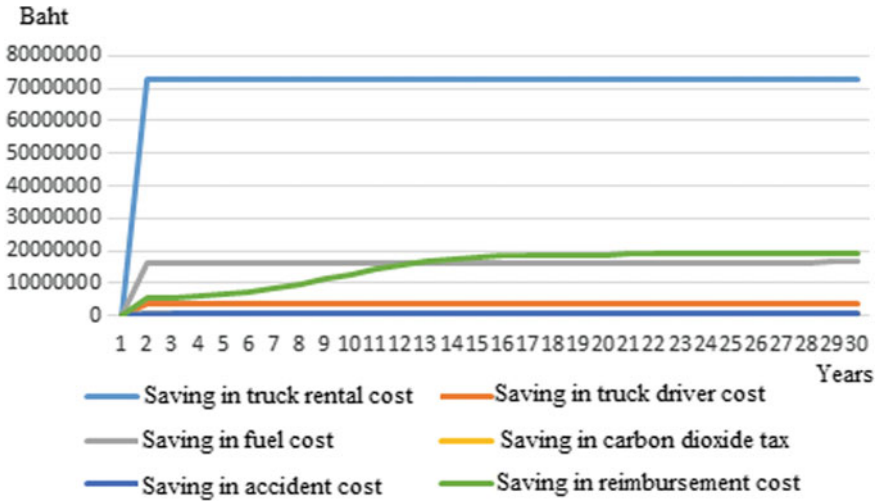


Fig. 3 Simulation results of saving factors

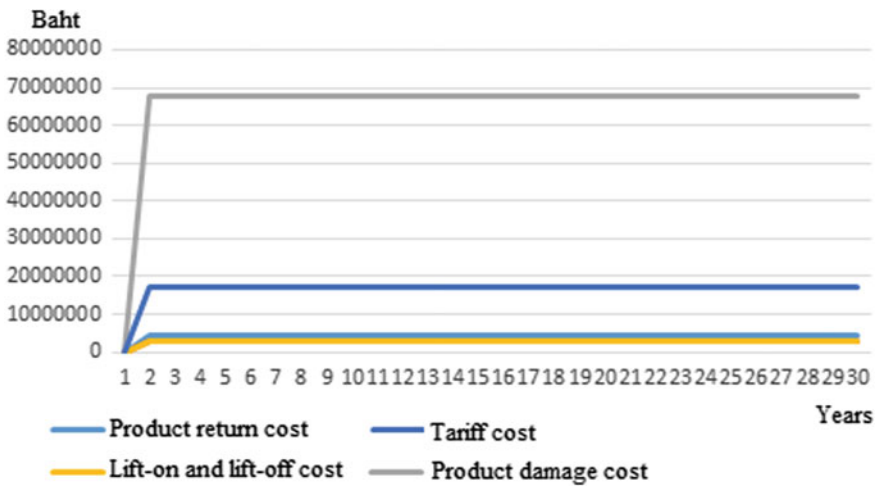


Fig. 4 Simulation results of cost factors

most of the government project is set at 12%. Figure 5 shows that with the continuous use of multimodal transportation, the project reaches the IRR of 12% at the end of year 13. The IRR keeps increasing afterwards and reaches 17% in 30 years.

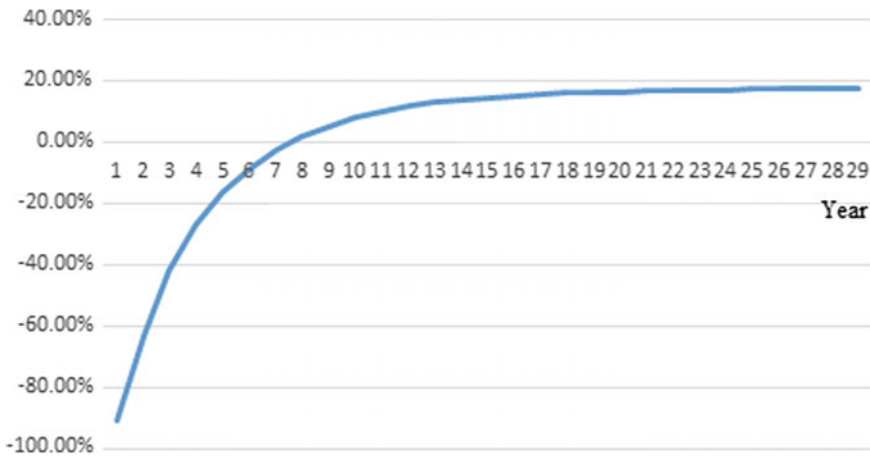


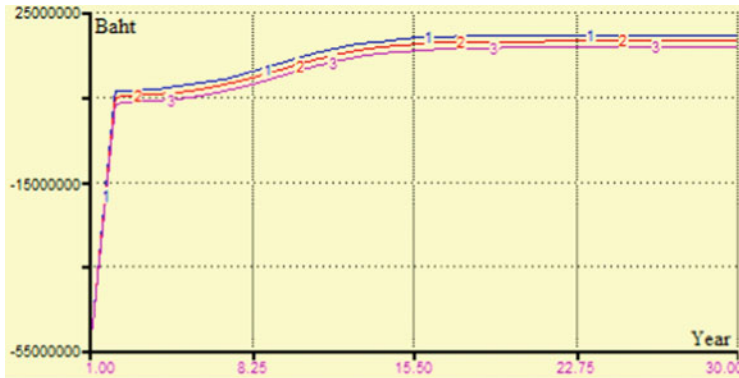
Fig. 5 Simulation results of internal rate of return

5 Sensitivity Analysis

To validate the model, this study uses the sensitivity analysis. Based on Fig. 3, the saving in truck rental cost is the most important saving factor. It is thus used to perform the sensitivity analysis to detect the sensitiveness of the developed SD model by changing the truck rental costs from 3.65 million–4.2 million baht (J&P Transport 2018). Figure 6 reveals that when changing the truck rental costs, the behavior of the model does not change, proving the non-sensitiveness of the model. The results also show that the multimodal transportation is effective when the current truck rental cost is very high. This is because high saving in truck rental cost is achieved when modal shift is utilized.

6 Conclusion

Becoming the center of transportation in the AEC, Thailand aims to utilize more of multimodal transportation to enhance the transportation effectiveness and reduce the logistics cost. This study develops the SD model of multimodal transportation of rubber products in Thailand, utilizing the SD modeling approach. Six savings, namely saving in accident cost, saving in reimbursement cost, saving in truck driver cost, saving in fuel cost, saving in truck rental cost, and saving in carbon dioxide tax, and five costs, including product return, lift-on and lift-off, tariff, and product damage costs are considered in the SD model. The simulation results reveal that the net cash flow is negative in the beginning years due to high investment in the container yard at the railway station to accommodate the transportation of rubber



Note: 1 represents the net cash flow when the truck rental cost is 4.20 million baht/year
 2 represents the net cash flow when the truck rental cost is 3.92 million baht/year
 3 represents the net cash flow when the truck rental cost is 3.65 million baht/year

Fig. 6 Sensitivity analysis results when truck rental cost is changed. *Note* (1) represents the net cash flow when the truck rental cost is 4.20 million baht/year, (2) represents the net cash flow when the truck rental cost is 3.92 million baht/year, (3) represents the net cash flow when the truck rental cost is 3.65 million baht/year

products in the long-term. The net cash flow becomes positive after the multimodal transportation is effectively used, with the IRR reaching 12% at the end of year 13.

It is found that with the use of multimodal transportation, less trucks are required, leading to high savings in truck rental cost and low carbon dioxide emission. The products, however, may have a higher chance of being damaged during the transshipment processes. Sensors may be installed to the packaging to warn rough handling and possible contents damage (Solistica 2018). The study results can be used as a guideline for the rubber and exporting companies to effectively plan for the multimodal transportation in the long-term. The government can also use the study results to plan for the infrastructure project to support the multimodal transportation.

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