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MODAL SHIFT TOWARD SUSTAINABLE VEGETABLES AND FRUITS SUPPLY CHAIN FROM VIETNAM TO CHINA USING DISCRETE EVENT SIMULATION

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Abstract
Modal shift is arguably an adequate solution to achieve sustainability goals for the supply chain (SC). It is particularly effective in economic and environmental dimensions when switching from road to sea and rail. Besides, this solution also creates a premise to take advantage of the benefits brought by the Belt and Road Initiative (BRI). This paper investigates the modal shift aspects for vegetables and fruits (V&F) SC from Vietnam to China, which accounts for 56% of the total turnover of the global ninth-largest V&F SC. The discrete event simulation (DES) approach conducted based on historical data indicates that replacing road haulage with rail and sea haulage can cut the total cost from USD 90.1 million to USD 96.7 million, and from 15.7 to 29.4 thousand tons of CO_2. Furthermore, network optimization integrated simulation demonstrates the optimal performance of a bi-modal solution. Additionally, the sensitive analysis implemented for bi-modal solutions suggests SC operators on the variations of economic and environmental indicators corresponding to fluctuations in shifted cargo volume.
Keywords: modal shift, sustainable supply chain, discrete event simulation, vegetables and fruits

1. Introduction

Achieving higher levels of sustainability has always been a top priority of worldwide SCs. A variety of solutions have been researched and proposed to achieve this goal, and modal shift is one of the techniques that can improve this situation (Colicchia *et al*., 2017). Modal shift is not a new topic that many scholars have advocated. It mainly shifted from road haulage to sea haulage (Raza *et al*., 2020; Park and Suh, 2011), while a few scholars have focused on the potential switch from road to railway shipping (Behrends, 2017; Regmi and Hanaoka, 2015). According to Sitek and Wikarek (2015), the primary challenge of SC operators is to maintain a consistent and undisrupted cargo flow and financial indicators while minimizing costs. Modal shift contributes to solving this challenge, and is presented in this study.

V&F SC plays an increasingly important role in nutritious diets and, thus, human health (Parajuli *et al*., 2019). Vietnam is currently the ninth-largest exporter of V&F and aims to be in the top five worldwide in the 2021-2030 period, as proposed by the Ministry of Agriculture and

Rural Development. China has been Vietnam's largest market for many years, even outnumbering all other markets combined. Figure 1 depicts China as the dominant market compared to the rest, with a turnover of USD 1.84 billion, accounting for more than 56 percent of total V&F exports of Vietnam in 2020. With a large and stable transaction volume annually, it is transported by container trucks through border gates between the two countries. This mode pollutes the environment and costs more than ocean railway shipping, even on short routes (Medda and Trujillo, 2010). In addition, the SC has also suffered from disruption many times due to border trade management policies. Thus, switching shipping modes from road to sea and rail can provide the potential for profit while also achieving environmental goals and SC transparency. This paper aims to study modal shift aspects of improving the sustainability of the V&F SC. Using the DES approach based on historical data, the financial and environmental dimensions of the SC are evaluated for each alternative.

The rest of this paper is set out as follows. Section 2 provides an overview of related works on modal shift and the DES approach in SSC. Section 3 describes the collected data and modeling configuration for DES experiments. In Section 4, the numerical testing is presented to analyze the economic and environmental dimensions for SSC. Furthermore, the network optimization is employed for bi-modal solutions to improve the performance of V&F SC. Furthermore, the sensitive analysis is conducted in this section to investigate the variation of output of bi-modal corresponding to shifted cargo volume. Section 5 contains the conclusions.

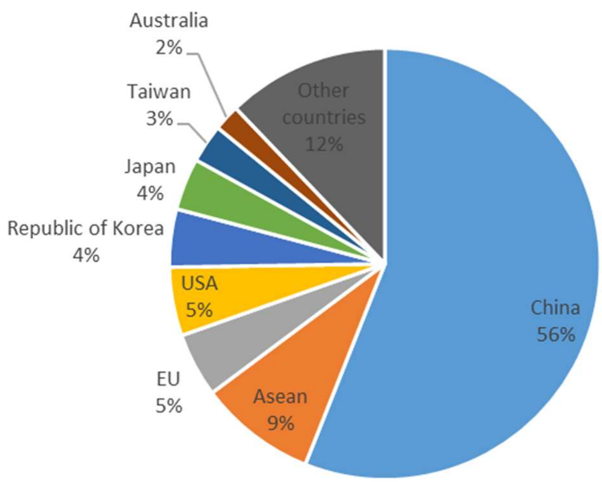


Figure 1: V&F exporting market share of Vietnam in 2020 (Source: Vietnamese Customs Authority).

2. Relevant studies

2.1 Sustainable supply chain (SSC) and DES approach

2.1.1 Literature on SSC

The literature on SSC is abundant. Most previous studies have focused on two dimensions of economic and environmental protection. Seuring and Müller (2008) and Jakhar (2015) developed a model that integrated structural equation modeling, fuzzy analytical hierarchy process, and fuzzy multi-objective linear programming for a survey dataset from 278 business organizations. The linkages between sustainability performance and SC decisions that allowed setting coherent performance measures were designed by Boukherroub *et al*. (2015). Narimissa *et al*. (2020) identified sustainability issues and the most crucial sustainability indicators using the meta-synthesis approach. An investigation of sustainability practices on SC risk utilizing a dataset from 21 different countries found that sustainability efforts could sometimes be more supportive than risk mitigation strategies for mitigating SC risk, especially in emerging market contexts (Gouda and Saranga, 2018).

The V&F SC plays a vital role in human health around the world. Therefore, the sustainability of this SC is receiving increasing academic attention. Tort *et al*. (2022) provided a systematic overview of sustainable V&F SC, including 118 selected articles, 6 of which are about logistics solutions, and 7 of which are about the sustainability of the V&F SC. In terms of research methods, these studies mainly use four methods: life-cycle assessment (LCA), equilibrium models, multi-criteria decision making (MCDM), and analytical hierarchy process (AHP). These are also four popular categories of models for the topic of SSC, according to Seuring (2013).

2.1.2 DES approach

Some studies use simulation tools for SSC. An integrated tool of simulation, risk assessment, and planning for food safety was calibrated to predict the spatial distribution and public health risks associated with contaminated food (Leblanc *et al*., 2015). Zoellner *et al*. (2018) utilized the postharvest SC with microbial travelers tool to simulate tomato SC from Mexico to the US. Another computer simulation tool, FlexSim, was employed to analyze the SSC's economic and environmental aspects (Hoffa-Dabrowska and Grzybowska, 2020).

The simulation method DES can flexibly analyze the SC performance by events and overtime periods. DES embedded in the ALADIN^{TM} simulation platform was proposed to illustrate the benefits of speed and quality of decision making and creativity of alternatives (Van Der Vorst *et al*., 2009). The potential use of DES was confirmed to capture the dynamic nature of the current SC configuration and operation (Byrne *et al*., 2010). Ivanov (2018) applied DES to determine the sustainability variables that can positively or negatively influence the SC's ripple effect. In another application of DES, Kogler and Rauch (2020) introduced a contingency planning toolbox to consider the outcomes of decisions before fundamental, costly, and long-lasting changes on an operational level.

2.2 Modal shift

Modal shift is not a new conceptualized terminology. For the past decades, it has been used as one of the practical initiatives toward the decarbonization target. Collectively, road shipping has several benefits, such as flexibility, frequency, and scheduling. Numerous researchers have proposed alternate methods based on biofuels (Van Wee *et al*., 2005; Dunn, 1995). However, the effects of carbon emission mitigation are not always as favorable as the proposed solutions (Tacken *et al*., 2014). Therefore, most relevant studies signified the importance of replacing high-carbon modes of transport, such as road transport, with lower-carbon modes, typically seaborne shipping or rail (Sanchez Rodrigues *et al*., 2015; Eng-Larsson and Norrman, 2014). Woodburn (2003) indicated that the modal shift from road to rail can potentially mitigate the negative impacts of transport on the environment. Tsamboulas *et al*. (2007) emphasized the need for an intermodal transport policy and the positive impact of a modal shift on SC in Europe. Colicchia *et al*. (2017) investigated the adoption of intermodal transport to operate SC using a Lean and Green approach. Using a case study of Italian Fast Moving Consumer Goods SC, they found that it is possible for a modal shift from road freight transport to a railway system. A new conceptualized framework, so-called "Synchromodality", was developed to allow shippers to operate their SCs flexibly to promote modal shift potential (Dong *et al*., 2018).

To the author's knowledge, studies applying the DES approach to investigate modal shift models' aspects are relatively rare in the literature. Furthermore, the application of this simulation technique to the modal shift solution for a sustainable V&F SC between Vietnam and China, which is an important SC with a high and stable turnover, is lacking. Therefore, this research contributes to academia and the green food SC operators as follows: (1) based on historical data to simulate the performance of SC in the base case (road shipping) and two modal shift cases (ocean and railway shipping); (2) use financial and environmental KPIs to indicate the benefits of two modal shift cases compared to the base case; (3) implement network optimization to identify a bi-modal solution that can help SC operators to improve performance efficiency.

3. Methodology

DES is a commonly used method to examine the effectiveness of a proposed decision at the operational/tactical level (Tako and Robinson, 2012). This study employs a compelling DES simulation platform called anyLogistix (Studio Edition) and financial and environmental KPIs for the performance of V&F SC and cases as described below.

3.1 V&F SC description

In this study, we examine the V&F SC with its starting point from farms to merchants in mainland China. Figure 2 presents a schematic diagram of the existing SC (base case) and two modal shift alternatives.

The existing SC (or base case) comprises acquiring fresh V&F from farmers and cooperatives (procurement module), processing, packing, and preservation at factories (processing module), and shipping to importers (delivery module). Accordingly, all shipping linkages between farms or cooperatives to factories, from the factories to the border gates, and from the border gates to the importers' warehouses, are by road. Most Vietnamese firms select this shipping method due to its flexibility, door-to-door delivery, and saving costs for multiple loading. It also allows for sequential delivery without bulking. However, compared to sea and rail, road transport has significant drawbacks, such as low custom clearing capacity, expensive transportation costs for long distances, and higher potential for environmental pollution. As a result, as illustrated in Figure 2, two choices might be given. Due to transportation infrastructure constraints, the only way to connect farms and cooperatives to the factories is by truck. V&F, after being processed and packed at factories, will be shipped to nearby seaports or railway stations. Road-haulage is replaced by sea-haulage (alternative 1) or rail-haulage (alternative 2) to bring goods to China's destination ports or stations. The containers are finally hauled to the enterprises' warehouses by truck.

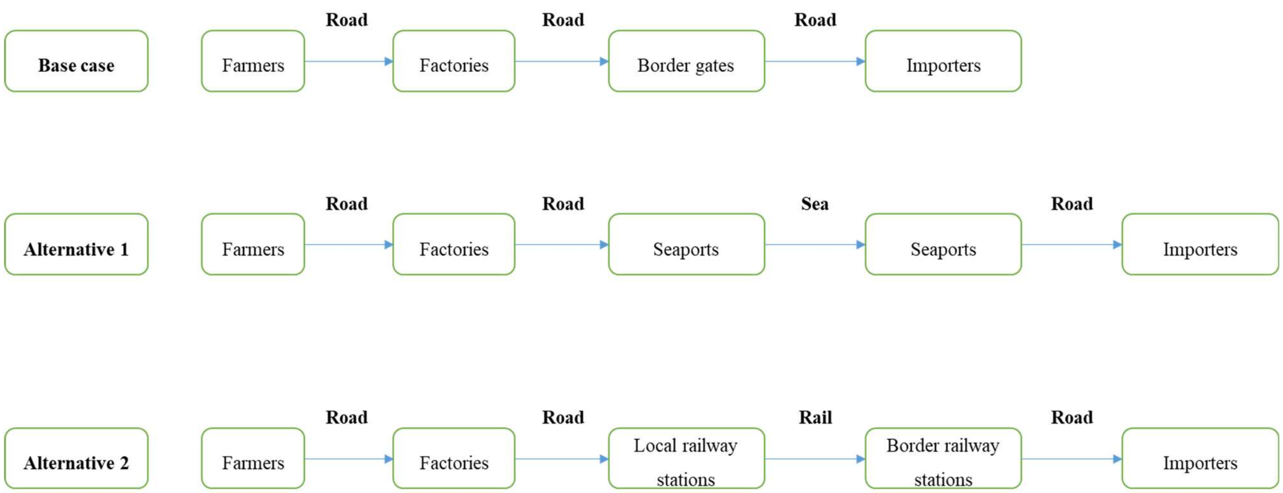


Figure 2: Schematic diagram of V&F SC cases.

3.2 Data and modeling approach

3.2.1. Data acquisition

Input data of simulation experiments on V&F exports were obtained from the Customs Authority of Vietnam and factories from January to December 2018. The data comprise customs declaration number, declaration time, HS code, bill of lading number, commodities information including the quantity, unit price, total value, procurement cost, delivery terms (Incoterms® 2010), name, contact, and address of exporters and importers, tariff, information of shipping vehicles, name of border gates, railway stations, and seaports. In addition, the list and location of areas (including latitude and longitude) for growing and packing V&F were obtained from the Plant Protection Department.

3.2.2. SC nodes and paths

The locations of nodes, including 26 suppliers (farms), 26 sites (5 factories, 5 border gates, 9 departure and arrival seaports, 7 local and border railway stations), and 204 customers are identified based on longitude and latitude on the GIS map.

We configured the parameters of the paths between the nodes separately for each leg. The paths from farms to processing plants in the three cases are the same and by small trucks. The author assumes that the freight for these paths using 7-ton trucks is USD 14.7, USD 15.3, and USD 16.4 per ton in South, North, and Central Vietnam. Since the products on these routes are transported by road that uses the distance verified by the GIS map, the straight distance mode was disabled. Therefore, the shipping time was not configured because the system automatically computes this parameter based on the GIS distance and trucks' speed (presumed to be 50 km/h).

For the paths from factories to border gates and customers (in the base case), from factories to nearby seaports and from seaports to customers (in alternative 1), and from factories to local railway stations and from foreign railway stations to customers (in alternative 2), the used vehicles should be container trucks with the assumed speed of 50 km/h.

The paths between railway stations were incorporated into the simulation tool using a GIS map. However, since the GIS map could not specify the distance between seaports' paths, we proceeded to enter the actual distance based on SeaRates.com (2021).

3.2.3. Demand, products, and inventory

The demand parameter was set according to historical data with exact quantity and revenue being imported from collected data. The selling price of each item was entered corresponding to each customer based on the unit price column in the database. Product procuring unit costs were configured based on the data gathered from factories. The descriptive statistics of these parameters are provided in Section 4.1. We follow an (s, S) inventory policy for suppliers and factories because suppliers' manufacturing capability and warehouse capacity are limited.

3.2.4. Sourcing, loading, and unloading cost

The sourcing policy differs depending on the leg. There are three production complexes located in the North, Central Vietnam, and the South. Factories have a consistent source of procurement from adjacent farms, located at a distance of 45.6 km on average and 97 km at most. Therefore, we administered the closest policy (dynamic sources) in this leg. Similarly, this policy is also applied to the two legs: (a) from the factories to the loading ports and railway stations (alternative 1 and 2); and (b) from the unloading ports and the railway stations to customers. The source policy for the leg from loading ports or stations to the unloading ports or stations follows the “split by ratio” policy. The "uniform split" policy is utilized for sourcing from factories to border gates and customers for the base case.

Loading and unloading costs in alternatives 1 and 2 are higher than the base case due to more transhipments. In the base case, the expense of moving containers between two container trucks at the border gates or lowering the containers to the customer warehouse is roughly USD 15 per TEU. When shifting to ocean shipping, businesses have to bear various cargo handling fees, local charges, and port fees such as document fees, THC (Terminal Handling Charge), CIC (Container Imbalance Charge), and cleaning container fees. These costs are bundled together as a logistics cost, since factories sign contracts with logistics service providers to handle this stage. This logistics cost is recorded at an average of USD 201.3 per TEU. For rail haulage, since the transport cost comprises the container handling fee, the inbound and outbound shipment expenses at the local stations could not be configured. However, the transfer station near the border region incurs an extra transfer cost, which is roughly USD 16.4 per TEU on average.

3.2.5. CO_2 emissions modeling

To estimate the total CO_2 emissions from V&F SC, we estimated energy consumption from the trucks, container trucks, ships, and trains beforehand. Then, the CO_2 emissions were estimated for each shipping mode using emissions factors as follows.

$$E_{mode} = EC_{mode} \times EF_{mode} \tag{1}$$

where EC is energy consumption; the unit of energy consumption depends on the estimation model for each vehicle, which can be described as in Equations (2), (4), and (6);

$mode$ is shipping modes including small trucks, container trucks, trains, and container ships.

EF is the CO_2 emissions factor. It was assumed to be 2.64 kg L^{-1} oil for trucks using diesel oil (Lin, 2019); 3.1 ton/ton fuel for container trucks and container ships using heavy fuel oil (HFO) (Endresen *et al*., 2003; Song and Xu, 2012); and 6.96 kg GJ^{-1} for trains using diesel oil (Jørgensen and Sorenson, 1998; Kim and Van Wee, 2009).

Trucks and container trucks

Energy consumption from road shipping (in liters, L) for each truck equals the sum of energy consumption in the delivery and empty legs, as in the following formula:

$$EC_{truck} = \left[ec_{empty} + (ec_{full} - ec_{empty}) \times CLF \right] \times D_{delivery} + ec_{empty} \times D_{empty} \quad (2)$$

where $CLF = Weight_{truck} / capacity_{truck}$. (3)

As mentioned above, we assumed that 7-ton trucks were used, which are commonly used to ship V&F from farms to factories; then, we obtained (ec_{full}; ec_{empty}) = (22.5; 11.1) for 7-ton trucks, and (41.0; 16.0) for container trucks.

Container ships

CO_2 pollution is modeled based on fuel consumption per container model adopted by the International Maritime Organization (IMO) (NTM, 2021a).

$$EC_{ship} = ec_{ship-dwt} / (PDR_{ship} \times CLF_{ship}) \times Weight_{ship} \times D_{ship}, \quad (4)$$

$$ec_{ship-dwt} = \alpha \times dwt^{-b} \quad (5)$$

where D_{ship}: distance was obtained from SeaRates.com (2021);

PDR_{ship}: payload dwt ratio (NTM, 2021d);

CLF_{ship}: cargo load factor of the container ship (NTM, 2021c);

α , b: regression constants for container ships conducted by the IMO (NTM, 2021a, 2021b).

Trains

Since railway shipping in Vietnam is completely diesel-powered, in this study, we used the estimation model for diesel trains as follows:

$$EC_{diesel-train} = \left(a \times \frac{V^2}{\ln(x)} + b \right) \times Weight_{diesel-train} \times D_{diesel-train} \quad (6)$$

where a and b: constants; a = 0.019 and b = 63 (Jørgensen and Sorenson, 1998; Kim and Van Wee, 2009);

V: average train speed, assumed to be 40 km/h;

x : average distance between stops; from 12.5 to 78.6 km; x = 56.4 km;

$Weight_{train}$: total weight of locomotive, wagons, container tare, and cargo.

Since in China, the electrification of railway has proceeded at a remarkable rate and became the primary sources for railway shipping, the CO_2 emissions modeling follows equation (7) (Corbett *et al*., 2012; Lättilä *et al*., 2013; Steenhof *et al*., 2006; Cristea *et al*., 2013):

$$E_{electric-train} = D_{electric-train} \times Weight_{electric-train} \times EF_{electric-train} \quad (7)$$

where $EF_{electric-train} = 22.7 \times 10^{-6}$ (ton/ton-km).

4. Results

4.1 Descriptive statistics

Tables 1-3 show the descriptive statistics of quantity, procurement unit cost, and sale unit price of V&F categories. Generally, the quantity of fruit slightly outnumbers the demand of vegetables. On the other hand, vegetable deliveries outnumber fruit orders by a factor of two (721 compared to 391). In terms of overall output, dragon fruit has the highest total quantity (32,093 tons), while bananas have the lowest position (roughly 4029 tons). Dragon fruit output is eight times higher than banana output, while the number of deliveries is only about 3.5 times (41 orders of dragon fruit compared to 12 orders of bananas). Dragon fruit is likewise the item with the most significant order, accounting for more than 2000 tons, while lemon has the smallest order, accounting for only 9.87 tons.

The procurement unit cost fluctuates strongly between min and max orders. The difference between the min-max unit cost of the lemon item is the largest (USD 1.27), in terms of absolute value, equivalent to more than six times (see Figure 3). This difference in the relative value of chayote is the highest, up to more than seven times. The durian fruit, which has the lowest difference, is 2.7 times. The following factors contribute to such a significant fluctuation: (1) Diversity in the quality of procured products. Despite having the same product name, the standards for the type and quality of product are different. (2) Regional variations. Essentially, vegetables in the southern region are less expensive than those in the central and northern regions. (3) Effect of the weather. The northern region's V&F harvests are out of season during the winter; hence, the price is substantially greater than during other seasons. (4) Due to the relatively low value of V&F, price volatility is particularly significant when economic events such as shortages or excesses of supply occur. On the other hand, due to the lack of geographical variances and weather swings for items cultivated solely in the southern area, such as durian (year-round temperature in the southern region is relatively stable), the procurement cost of durian is substantially lower than that of other items. Meanwhile, the range in selling prices to customers in China is substantially smaller than the volatility in procurement cost and is reasonably steady across all items, varying from 1.26 to 2.21 times.

Table 1: Descriptive statistics of quantity (tons).

Groups	Commodities	Min	Max	Mean (SD^1)	Total
Vegetables	Water Cress	28.93	1092.00	712.46 *(220.97)*	24,003.48
	Mustard Greens	12.03	567.39	270.38 *(98.70)*	27,038.27
	Water Spinach	14.98	402.89	209.45 *(101.32)*	18,392.95
	Celery	49.07	940.80	561.07 *(143.97)*	25,028.36
	Lettuce	15.64	236.58	106.37 *(47.23)*	8039.04
	Coriander	43.90	397.12	98.67 *(58.69)*	10,937.81
	Chayote	73.28	879.01	654.39 *(196.50)*	5209.03
	Total				**118,648.94**
Fruits	Dragon Fruit	109.65	2047.40	1228.98 *(597.81)*	32,093.16
	Mango	150.38	785.90	346.91 *(105.43)*	19,826.67
	Banana	24.38	1893.05	756.65 *(399.76)*	4029.29
	Coconut	13.68	1294.04	650.37 *(409.82)*	28,370.46
	Watermelon	201.76	873.94	498.01 *(276.13)*	16,792.17
	Jackfruit	56.09	874.63	309.86 *(128.97)*	4039.42
	Lemon	9.87	1409.67	777.91 *(404.35)*	7937.30
	Durian	150.23	1109.40	663.05 *(496.81)*	9837.63
	Passion fruit	27.39	567.42	325.97 *(119.86)*	11,028.02

Total	**133,954.12**
Total	**252,603.06**

[1] Standard deviation (SD)

Table 2: Descriptive statistics of procurement unit cost (USD).

Groups	**Commodities**	**Min**	**Max**	**Mean (*SD*)**
Vegetables	Water Cress	0.15	0.54	0.30 *(0.29)*
	Mustard Greens	0.14	0.49	0.21 *(0.22)*
	Water Spinach	0.15	0.71	0.32 *(0.36)*
	Celery	0.21	0.82	0.47 *(0.41)*
	Lettuce	0.23	1.21	0.89 *(0.27)*
	Coriander	0.15	0.50	0.30 *(0.18)*
	Chayote	0.10	0.72	0.35 *(0.33)*
Fruits	Dragon Fruit	0.23	1.17	0.54 *(0.61)*
	Mango	0.21	0.98	0.39 *(0.51)*
	Banana	0.28	0.88	0.57 *(0.25)*
	Coconut	0.07	0.45	0.22 *(0.29)*
	Watermelon	0.07	0.48	0.23 *(0.24)*
	Jackfruit	0.19	1.09	0.43 *(0.36)*
	Lemon	0.25	1.52	0.63 *(0.44)*

	Durian	0.64	1.73	1.07 *(0.69)*
	Passion fruit	0.16	0.77	0.25 *(0.37)*

Table 3: Descriptive statistics of sales unit price (USD).

Groups	**Commodities**	**Min**	**Max**	**Mean (*SD*)**
Vegetables	Water Cress	1.17	1.92	1.52 *(0.64)*
	Mustard Greens	0.70	1.43	0.98 *(0.37)*
	Water Spinach	0.82	1.81	1.11 *(0.75)*
	Celery	1.46	2.84	2.08 *(0.69)*
	Lettuce	1.66	2.09	1.92 *(0.39)*
	Coriander	1.04	1.99	1.79 *(0.31)*
	Chayote	0.72	1.46	0.95 *(0.61)*
Fruits	Dragon Fruit	2.16	2.88	2.50 *(0.42)*
	Mango	2.47	3.33	3.04 *(0.77)*
	Banana	1.18	1.87	1.54 *(0.46)*
	Coconut	0.89	1.64	1.21 *(0.53)*
	Watermelon	1.05	1.95	1.48 *(0.62)*
	Jackfruit	1.53	2.75	2.06 *(0.84)*
	Lemon	2.48	3.55	3.12 *(0.79)*

Durian	3.56	5.17	4.03 *(1.13)*
Passion fruit	0.95	1.86	1.50 *(0.45)*

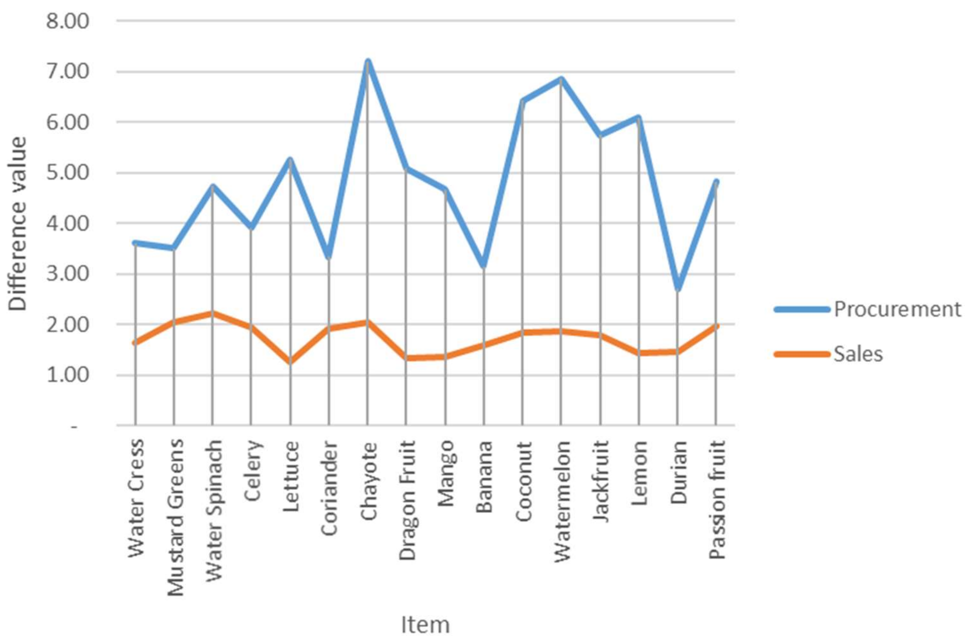
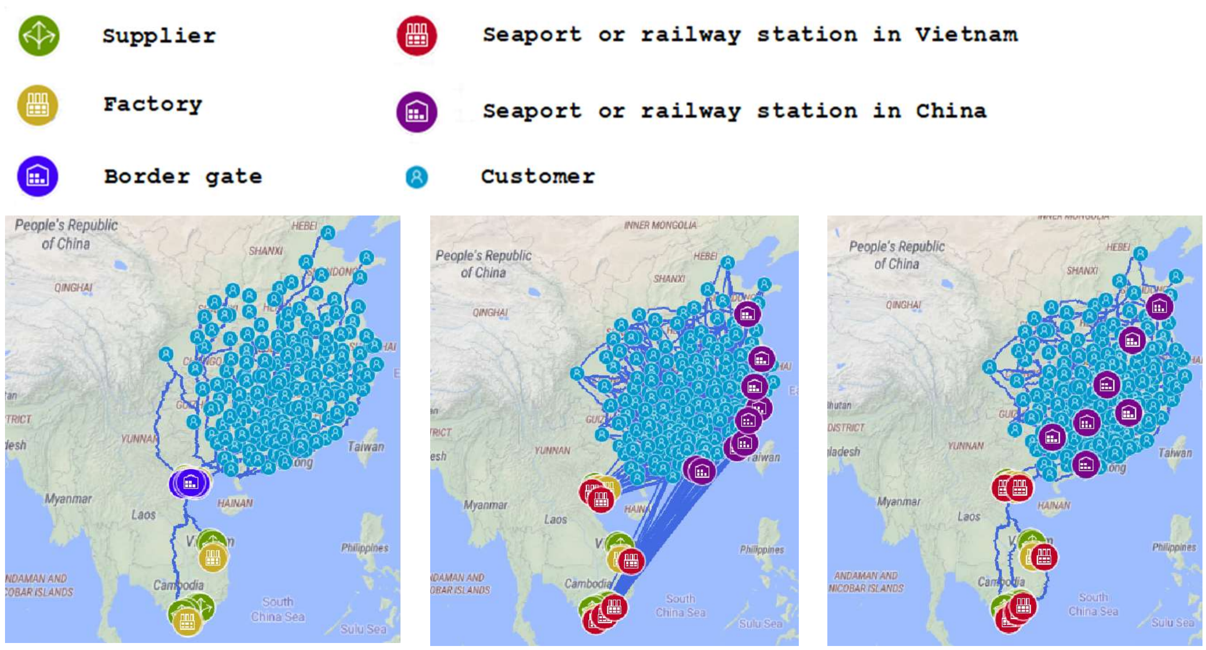


Figure 3: Difference between max and min value of unit price (times).

4.2 Simulation results and modal shift aspects

The simulation maps for three cases are presented in Figure 4. As seen in the base case, all commodities are concentrated at the land border gates between the two countries and subsequently distributed to customers spread over the continent. Thus, the border gate area acts as a bottleneck for goods circulation. This is a disadvantage when one of the two nations' authorities decides to close the border. In fact, in the past, the Chinese authority has conducted annual border closure operations many times. This temporarily interrupted the SCs of Vietnamese enterprises, and tens of thousands of containers were congested after being shipped to the nearby border region, sometimes up to several months. This congestion is particularly damaging to perishable products such as V&F. As a result, products have to be returned to be sold in the domestic market at a low price, sometimes down to 1/10, or even destroyed. This disadvantage can be solved when shifting to sea haulage or rail haulage. Moving distribution sites further into mainland China could avoid the consequences of bottlenecks.



a) Base case　　b) Alternative 1　　c) Alternative 2

Figure 4: Simulation process of SC based on GIS map (screenshot by author from anyLogistix).

Furthermore, financial KPIs and CO_2 emissions output are better with maritime or railway shipping than with total road shipping. The performances of V&F SC in three cases are shown in Tables 4-6. Figure 5 illustrates financial KPIs for the three cases. Accordingly, in the base case, the profit margin for vegetables is up to 30.5%, while the index for fruit is only 15.7% and for both products is around 27.4%. As expected, switching to maritime shipping means that if the selling price remains the same, the profit can increase from 43.9 million to 89.5 million, from 22.2 million to 73.2 million, and from 66.1 million to 162.8 million for vegetables, fruits, and total V&F, respectively. That is, the profit margin improves by double for vegetables (from 30.5% to 62.2 %), three times for fruits (from 15.7% to 45%), and twice for both categories (27.4% to 53%). This index for railway shipping (alternative 2) is also approximated to sea haulage (alternative 1), at 60%, 42.7%, and 50.8%, respectively.

Table 4: Performance of SC in the base case.

	Cost (USD)	Revenue (USD)	Profit (USD)	CO_2 emissions (tons)
Vegetables	100,099,376.41	143,924,400.00	43,900,623.59	15,869.96
Fruits	140,908,071.77	163,130,434.78	22,222,363.01	17,721.47
Total	**241,007,448.18**	**307,054,834.78**	**66,122,986.60**	**33,591.43**

Table 5: Performance of SC in modal shift case to sea (alternative 1).

	Cost (USD)	Revenue (USD)	Profit (USD)	CO_2 emissions (tons)
Vegetables	54,428,640.76	143,924,400.00	89,571,359.24	8458.58
Fruits	89,909,083.63	163,130,434.78	73,221,351.15	9445.41
Total	**144,337,724.39**	**307,054,834.78**	**162,792,710.39**	**17,903.99**

Table 6: Performance of SC in modal shift case to rail (alternative 2).

	Cost (USD)	Revenue (USD)	Profit (USD)	CO_2 emissions (tons)
Vegetables	57,520,281.35	143,924,400.00	86,479,718.65	1995.05
Fruits	93,361,415.62	163,130,434.78	69,769,019.16	2227.81
Total	**150,881,696.97**	**307,054,834.78**	**156,248,737.81**	**4222.86**

a) Base case

b) Altenative 1

c) Alternative 2

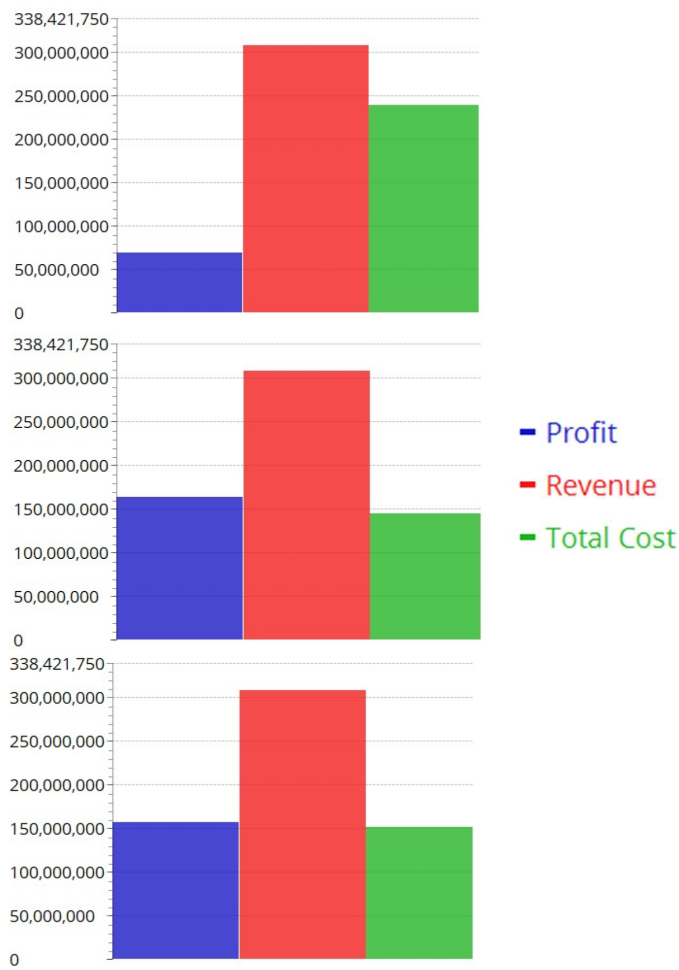
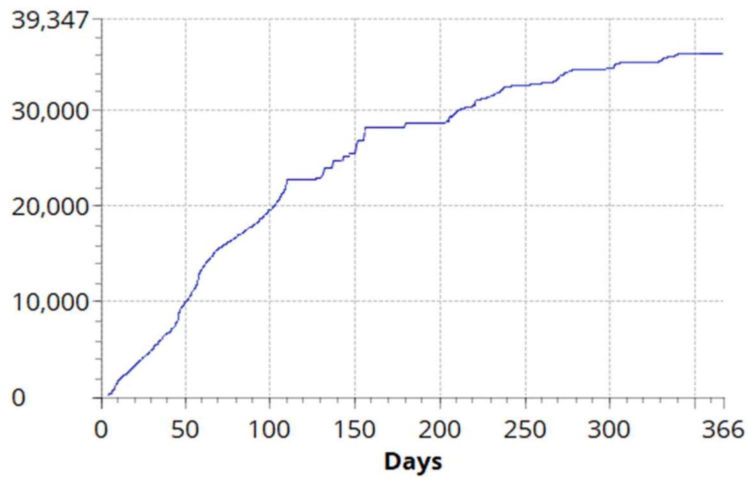


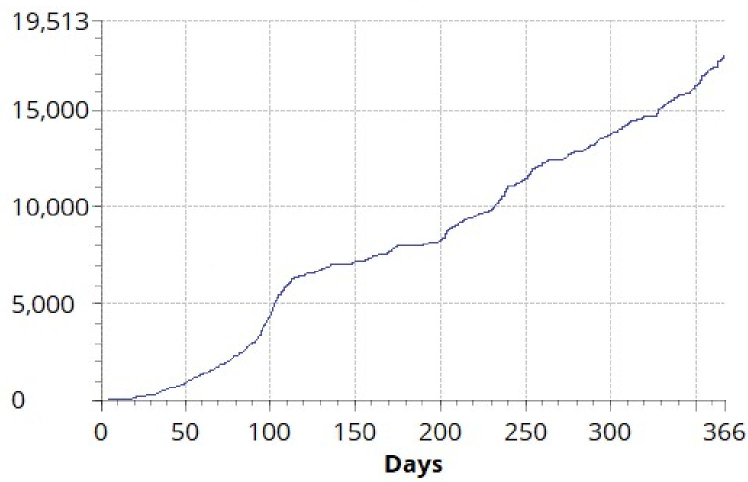
Figure 5: Financial KPIs of three cases (screenshot by author from anyLogistix).

Both alternatives emit much less CO_2 than road haulage (17,904 and 4223 tons instead of 33,591 tons) in terms of environmental indicators. In this regard, it is worth noting that railway shipping can cut CO_2 to one-eighth compared to the base case. Figure 6 shows the CO_2 production process for the study period. In the base case, the amount of CO_2 in the first 110 days climbed quite fast, indicating that the trucks' operational flow was very high throughout this period. The SC operates quite smoothly, and the throughput is fairly high. However, the slope steadily dropped afterward, illustrating the phenomenon of border commerce slowing down. There are even some time intervals that this line crosses, reflecting the congestion of the goods at the border gates due to the policy of the Chinese authority. For instance, between day 110 and day 130, day 155 to day 205, day 230 to 270, and so on, there was almost no increase in CO_2 from vehicles. This phenomenon is invisible when utilizing rail and sea transport, indicating that the bottleneck issue can be tackled and cargo flow is not congested. The concave curve shape depicts dense activities of trucks at the beginning, then diminishes to make way for ships and trains, and eventually there is a steep rise again as the trucks join in distributing products to customers.

a) Base case



b) Alternative 1



c) Alternative 2

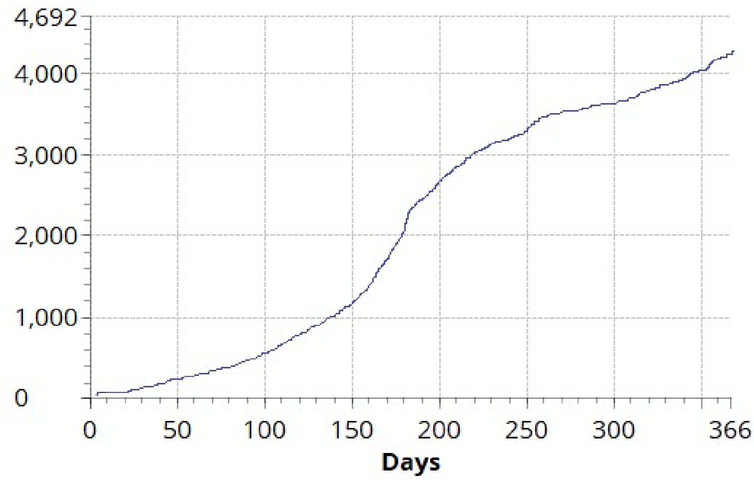
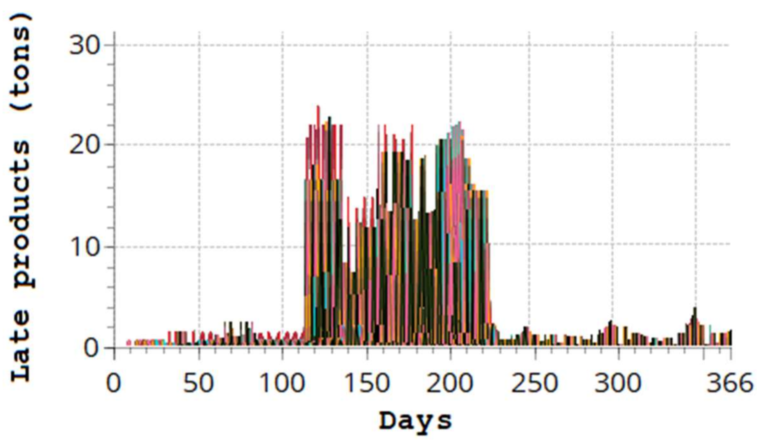
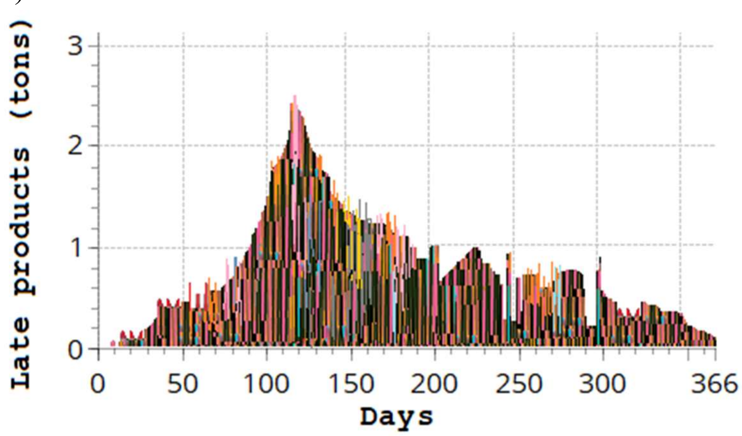


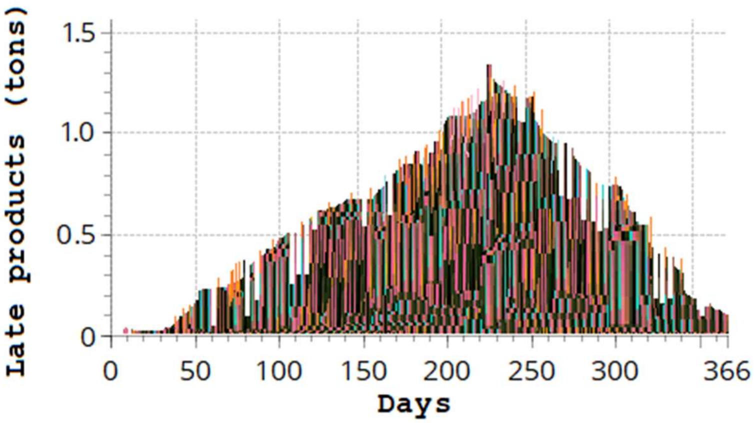
Figure 6: Production process of CO_2 emissions (screenshot by author from anyLogistix).



a) Base case



b) Alternative 1



c) Alternative 2
Figure 7: Daily late fulfilments of simulation (colored by product).

Figure 7 shows the daily fulfilment for late products in three cases. In the base case, due to the border trade restriction, shipments were severely congested in this region for an extended period from day 110 to day 220. Factories could not respond to the border closure policy promptly. This is why trucks continue to arrive en masse at the border. After this period, factories curtailed output, resulting in a considerable decline in the number of late products. Late fulfilment of products by sea and rail shipping has been greatly decreased because the congested issue no longer exists. The cumulative late products for the base case, alternative 1, and alternative 2 equal 41,452 tons, 8,215 tons, and 4,997 tons, respectively. Since the consolidation and release of goods for rail haulage are more flexible than for seaborne shipping on short routes (Zhang and Schramm, 2020), the number of late products for rail transport can achieve the minimum level of the three options.

4.3 Network optimization and discussion

As analyzed above, the modal shift to ocean and rail shipping could make the SC more sustainable than the current shipping mode, which is totally by trucks. Looking at the entire SC, the profit from both alternatives nearly doubled compared to the base case, in which the profit from seaborne shipping was somewhat more impressive (53% compared to 50.8%). Regarding the environment, railway shipping clearly has a significant benefit when the CO_2 decrease is high, only equalling 1/4 of the alternative 1 and 1/8 of the base case. Furthermore, moving to ocean and railway shipping can support minimize congestion, create smoothness, and eliminate order delays for the V&F SC.

The number of Vietnamese firms who have abandoned the practice of utilizing land transport and the volume of V&F exported to China by sea shipping has increased in recent years due to recognizing the benefits and stability that sea transport provides. From 2020 to now, due to the impact of the COVID-19 epidemic on the global SC and the "zero COVID" policy of the Chinese government, sea freight rates increased sharply, and shipping activities to Chinese ports were heavily influenced, and therefore the financial analysis in this study may be subject to uncertainty. However, the analysis of the environmental aspects remains valid. Moreover, after the epidemic outbreak is brought under control and countries enter the SC resilience phase, the economic benefits of alternative 1 compared to the base case are indisputable. On the other hand, due to inadequate rail transport infrastructure, particularly on the Vietnamese side, the railway shipping mode has only been tried with a few deliveries in a modest number. For example, the number of international railway stations and the warehouses and yards system is small, and the capacity of loading and unloading equipment, amenities, and operation frequency is fairly low. As a result, despite the high demand for railway shipping, most enterprises still prefer sea transport as a superior alternative. However, excluding political factors, the Belt and Road Initiative (BRI), led by the Chinese government, is believed to bring positive and significant benefits to ASEAN countries' trade (Foo *et al*., 2020; Yii *et al*., 2018). Additionally, Vietnam is in the centrality triangle in the global maritime network and plays an essential role in the BRI network, as indicated by Hu (2019) and Zhao *et al*. (2020). Therefore, the development and strengthening of the railway network in Vietnam and the ocean shipping system with the BRI network also arguably make many contributions to Vietnam and the region.

The combination of both sea and rail can also provide a harmonized solution for an SSC. In this section, we perform a network optimization analysis using a combination of rail and ocean freight to examine the variations in the indices. This optimization analysis can solve the current issue of purely deploying ocean or railway shipping. That is, there are several customers located in the central and western regions of China, which are fairly far from seaports. Therefore, a bi-modal case should become an effective solution.

For bi-modal analysis, we implement the network optimization function integrated into anyLogistix. If all customers in the central and western regions are shifted from ocean shipping to railway transport, the optimization system eliminates stations (Foshan, Leiyang, Taiyuan, and Linyi) and ports (Zhuhai, Xiamen, Fuzhou, and Ningbo). Thus, three stations (Guilin, Nanchang, and Huainan) and five ports (Shenzhen, Quanzhou, Wenzhou, Shanghai, and Rizhao) are retained for the shipping network. Table 7 demonstrates the performance of the bi-modal scenario after optimization based on the financial criterion. As a result, the profit can grow by approximately USD 8.7 million and 15.2 million compared to alternatives 1 and 2, respectively. In terms of the environmental dimension, the quantity of CO_2 pollution in the bi-modal case is also less than alternative 1 by roughly 8800 tons, which is very significant.

Table 7: Performance of bi-modal solution.

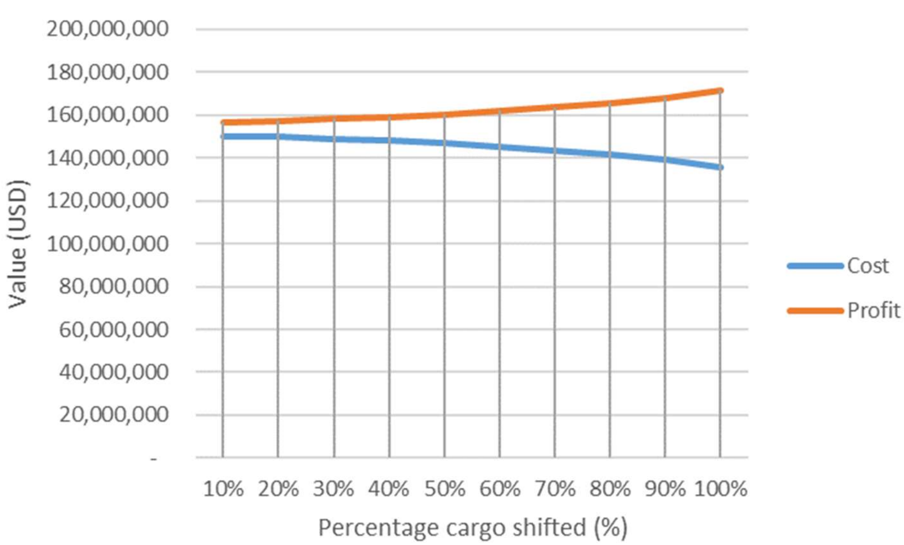
	Cost (USD)	Revenue (USD)	Profit (USD)	CO_2 emissions (tons)
Vegetables	49,827,829.15	143,924,400.00	94,096,570.85	3737.57
Fruits	85,739,729.80	163,130,434.78	77,390,704.98	5398.95
Total	**135,567,558.95**	**307,054,834.78**	**171,487,275.83**	**9136.52**

** Relative tolerance at 5% MIP (mixed integer programming) gap*

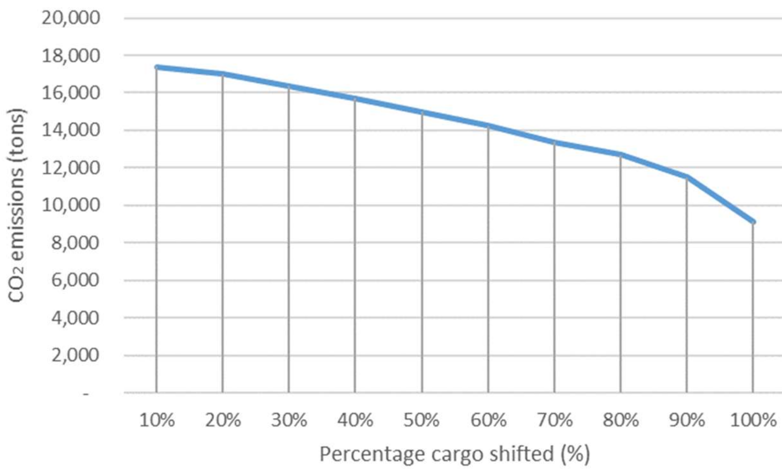
Table 8: Sensitivity analysis of bi-modal solution.

	CO_2 (tons)	Cost (USD)	Profit (USD)
10%	17,398.45	150,227,299.72	156,827,535.06
20%	16,994.32	149,772,902.46	157,281,932.32
30%	16,371.17	148,718,505.20	158,336,329.58
40%	15,726.90	147,964,107.94	159,090,726.84
50%	14,982.62	146,809,710.68	160,245,124.10
60%	14,238.35	145,055,313.43	161,999,521.35
70%	13,394.08	143,500,916.17	163,553,918.61
80%	12,694.80	141,546,518.91	165,508,315.87
90%	11,505.55	138,992,121.65	168,062,713.13
100%	9136.52	135,567,558.95	171,487,275.83

A sensitivity analysis is further undertaken to examine the extent to which economic and environmental changes occur corresponding to the variation in cargo volumes from ocean shipping to rail shipping (see Table 8). The percentage adjustment is applied exclusively to customers in the West and Central regions, not the whole customer list. Accordingly, the 100% level corresponds to the above-mentioned optimal bi-modal scenario. The convex shape of the cost curve and the concave shape of the profit curve indicate that the more volumes in the West and Central regions are shifted from sea haulage to rail haulage, the lower the costs and the greater the profits (see Figure 8). That is, by shifting from 11,176 tons to 22,352 tons of goods in this region, the SC's total profit may grow from 156.8 million to USD 157.3 million while reducing CO_2 emissions from 17,400 to 17,000 tons.



a) Financial KPIs



b) CO_2 KPIs

Figure 8: Financial and environmental KPIs corresponding to shifted cargo volume.

In addition, an issue that needs to be addressed in the sensitivity analysis is that, in this optimal layout of seaports and train stations, not all cases are more financially practical than alternative 1. As seen in Table 8, it is clear that only when 70% of the cargo volume in the area is handled by trains, the profit starts to exceed alternative 1. This phenomenon occurs because when the volume of goods hauled by trains is insufficient, the volume of road transport from seaports to distant customers remains high, creating a cost strain on the system. When reaching the threshold where 100% of customers in this area are distributed to from train stations, the density of freight traffic by trucks will be significantly reduced, as will the cost burden.

5. Conclusions

This study employs a DES method to assess the influence of modal shift solutions on the sustainable performance of the V&F SC under economic and environmental conditions. The simulation findings demonstrate that the switch to sea haulage (alternative 1) or rail (alternative 2) can enhance the SC's sustainability more than road haulage (the base case). Financial KPIs indicate that profits can be increased by USD 96.7 million when entirely using maritime shipping, and CO_2 emissions are reduced by 15,700 tons. This value when applying alternative 2 is USD 90.1 million and 29,400 tons of CO_2, respectively. On the other hand, reducing the volume of goods circulating through land border gates to switch to seaports and international train stations can solve the problem of SC disruption due to congestion at border gates. The evidence shows that the cumulative amount of late delivery decreased significantly from 41,452 tons to 8215 tons and 4997 tons for alternatives 1 and 2, respectively.

Although ocean shipping achieves more profit than railway shipping, the location of seaports distant from customers in the West and Central regions means that truck traffic from the ports to these locations is nevertheless dense. This opens up the potential for an optimal solution that can further cut shipping costs and eliminate CO_2 pollution. A bi-modal analysis is performed to further improve the operational efficiency of the SC by determining the best mix of ocean shipping and railway shipping with an objective function of profit maximization. When compared to wholly ocean shipping, this optimal bi-modal solution can save roughly USD 8.7 million in overall expenses and eliminate around 8,800 tons of CO_2, which is very significant. A sensitivity analysis was further conducted on the bi-modal solution to assess the variability of financial and environmental KPIs in response to fluctuations of shifted cargo volumes. As the volume of commodities shifted from sea transport to rail transport increases, so does the pace of reducing costs and CO_2. When the shifted percentage achieves the 70% benchmark, the profit levels off and exceeds the use of vessels case. This analysis is meaningful in demonstrating the relevance of railway shipping and the growing interest of corporations and governments in rail transportation. The finding is consistent with some studies in that it is vital to lower the density of road haulage by replacing it with maritime or rail haulage toward decarbonization (Kaack *et al*., 2018; Arioli *et al*., 2020). Rail haulage is even emphasized as cost-effective and cleaner than sea haulage (Salvucci *et al*., 2019). With such great benefits, railway transport needs to be invested in to enhance infrastructure so that the connection between the countries' railway networks is more convenient, making it more appealing for businesses to choose this solution for their SCs.

One limitation of this study is that it is based on historical transaction data provided by factories and the Customs Authority, so the number and locations of train stations as well as seaports in the study are not diversified. As a result, the solutions in this study are not globally optimal. Future studies can be carried out on a wider network of seaports and train stations and the performance of the SC can be much more optimized. Besides, the investment in infrastructure for train stations also needs analysis based on long-term and sustainable demand and cargo flow. This can be carried out with prediction and clustering algorithms with high accuracies, such as the machine-learning method. Future studies may be conducted on various commodities to support authorities in making more comprehensive investment decisions when data for other commodities are available.

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