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ROUTE SELECTION AND TRADE-OFFS EVALUATION OF THE INTERMODAL FREIGHT TRANSPORTATION

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Abstract

Identification of optimum routes and mode of transport play vital roles in freight transport decision making. This paper presents the research carried out for the modelling and analysis of intermodal transport network. The study evaluates the trade-offs associated with different modes of freight transportation. Geographic Information System (GIS) and MATLAB were applied to design the hypothetical intermodal freight transportation network, modelling, analysis and user-interface design. An optimum route and transport mode for different pairs of origins and destinations were determined across decision objectives such as distance, time, emission and cost. The trade-offs among different modes of freight transportation were explored. Based on the assumptions of this study, the results showed that the road was the fastest mode, while waterway was not only the most cost-efficient but also was the most environmental-friendly transport mode in terms of carbon dioxide emission. Although the transport network of the study was small size and hypothetical, this paper demonstrates the potentiality of this methodology for analysing larger and real intermodal networks.

Keywords: Freight transportation, Intermodal, Modal choice, Route selection, Transport modes.

1. Introduction

One of the major components of globalization is the transportation sector, which plays a very significant role in daily activities and the economy. During the 20th century, trade scale changed from local to global and therefore freight transport system became a global network. In particular, freight transportation is one of the today's most important economic activities. It is measured by its share of nation's

Nomenclatures

C_V	Capacity of the vehicle, TEU
C_W	Container weight, ton
E	Emission, tons
E_f	Emission factor, kg/ton-km
F_C	Fuel consumption, litre/km
F_p	Fuel price, RM/liter
Ma	Maintenance of the vehicle, RM/km
N_c	Number of containers
S_l	Speed limit, km/hr
Tc	Transport cost, Ringgits, RM
T_d	Travel distance, km
T_t	Travel time, hr
Wa	Wage of the driver, RM/hr

Abbreviations

CO	Carbon monoxide
GHG	Greenhouse Gas Protocol
GIFT	Geospatial Intermodal Freight Transportation
GIS	Geographic Information System
GNP	Gross National Product
NO_2	Nitrogen dioxide
PM_{10}	Coarse particulate matter
SO_2	Sulfur dioxide
TEU	Twenty-foot Equivalent Unit

Gross National Product (GNP) and by the increasing influence that transportation and distribution of goods have on the performance of many economic sectors like wholesale and retail trade, manufacturing and production, etc. Freight transportation involves the movement of commodities in a transport network from the origin to destination. This movement needs infrastructures like roads, railways, waterways and airways and vehicles such as truck, train, ship and aircraft. Quality, type, size and capacity of infrastructures and vehicles can directly impact on freight transportation. Intermodal freight transportation is the concept of transporting loads from origin to destination by a sequence of at least two transportation modes. The transfer from one mode to the next is often being performed at intermodal terminals [1]. Typically, the focus of intermodal freight transport is on surface transport [2-4]. In addition, some works have been carried out to make air transport as an alternative option in intermodal freight transport [5, 6].

Globally, the concerns of emission, fuel consumption and congestion from freight traffic are increasing at a more rapid rate than other types of transportation [7, 8]. Hence, freight transport is considered more censorious and critical than the past [9-13]. It has been reported by Chen et al. [14] that about 98 percent of containers in Malaysia are being transported by road, while others by rail. The increase in congestion on roads is due to more usage of trucks as a transport mode for commodities. This leads to deterioration of air quality and generates distress to residents and businesses in and around heavily travelled freight arterials. Although, freight terminals and ports are facing similar problems as roads.

Air emissions are caused by an increase in a number of goods being moved and the changes in the delivery services. There are numerous pollution problems associated with freight transportation [15-18]. These include the release of local and regional pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and coarse particulate matter (PM_{10}), as well as greenhouse gasses such as carbon dioxide (CO_2). Land freight sector in Malaysia contributes approximately 23% of the CO_2 emissions from the transportation sector (estimated to be 50 Mt of CO_2 in 2014) [19]. Carbon dioxide is a major contributor to greenhouse gas from burning fossil fuels, which leads to global warming and climate change. For instance, from 1948 to 2005, North America's surface temperature has increased by 1.2°C (2.2°F) [20]. It has been projected that average surface air temperature would increase from 1.1 to 6.4°C by the year 2100 [21].

Identification of an optimum route and mode of transport through intermodal transport network is very important. Research on this topic is essential since it can improve transport efficiency and level of service, time and cost reduction for goods delivery. This paper attempts to determine the shortest path and associated modes of transport for containers movement from the origin to destination in a hypothetical intermodal freight transport network based on different decision objectives. The decision targets for the study is to achieve the least distance, time, carbon dioxide emission and cost for the operation. This study also evaluates associated trade-offs between least time, least-emission, least-cost results with other alternative transport modes. Road, railway and waterway were considered as available modes of transport in which roads consisted of highways and federal roads. Each segment of the network assigned speed limit according to the associated transport mode. It is assumed that the assigned speed limit is constant from starting point to the end point of each segment. The time, emission and cost of modal change at intermodal points are not considered. It is also assumed that all segments are bidirectional path.

2. Literature review

A framework has been presented to analyze and evaluate intermodal networks in a GIS environment for auto and rail commuter networks [22]. The method used TransCAD to generate necessary files for the network analysis. Rowinski et al. [23] developed demand-forecasting model for assigning multi-commodity, multi-class truck trips between various origin and destination points. The model was basically formulated as a policy analysis tool for only highway mode. It was applied to assess the impacts of congestion on truck route choice implementation of TransCAD and Microsoft Access.

Standifer and Walton [24] presented similar research work with the different methodology in terms of intermodal network creation. Their model was applied to simulate intermodal freight transportation with geographic information system (GIS) feasibility demonstration and was able to perform a variety of analyses as a decision support system for shippers, planning agencies and researchers. The researchers created an intermodal network for Texas by merging each individual mode into one final intermodal network by using data conflation and several other techniques for each mode networks. Winebrake et al. [25] presented a Geospatial Intermodal Freight Transportation (GIFT) model developed through GIS platform to identify routes from origin to destination in an intermodal transportation network with emphasis on cost, time and emission. On the other hand, Comer et al. [26]

adopted GIFT model for investigating the impact of replacing marine vessels with heavy-duty trucks in the U.S. Great Lakes regions.

An intermodal transport network can be modelled as a directed graph using two types of interconnected components, nodes and arcs [27]. Nodes represent entities like sources, destinations and transport mode changing points. Arcs represent entities such as roads, railways, waterways, etc. Between two nodes, there might be one or more routes, each of which indicates a specific mode of transportation. Figure 1 shows an example of the intermodal transportation network in which the different line types represent different modes of transport.

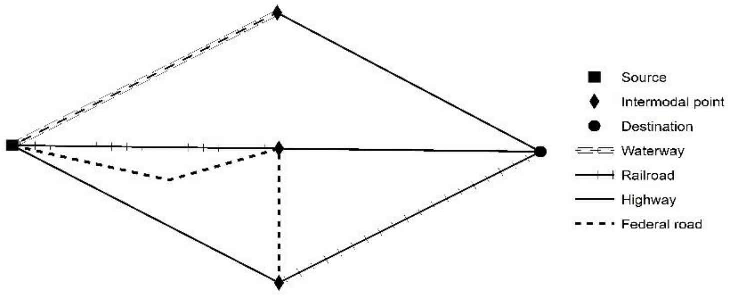

Fig. 1. Example of the intermodal transport network.

3. Methodology

The hypothetical transport network for this study is as depicted in Fig. 2 was constructed with the use of ArcMap, a GIS software which consists of point and polyline layers. Point layers comprised of sources, destinations, and intermodal points. Node no. 1 and 2 were considered as the origins, node no. 3 and 4 represented destinations, and node no. 5, 6 and 7 represented the intermodal points. Polyline layers consisted of roads (both highway and federal roads), railroads and waterways. Each arc between two nodes included attribute data. The content of attribute data was the length of arcs in kilometers and associated mode of transport.

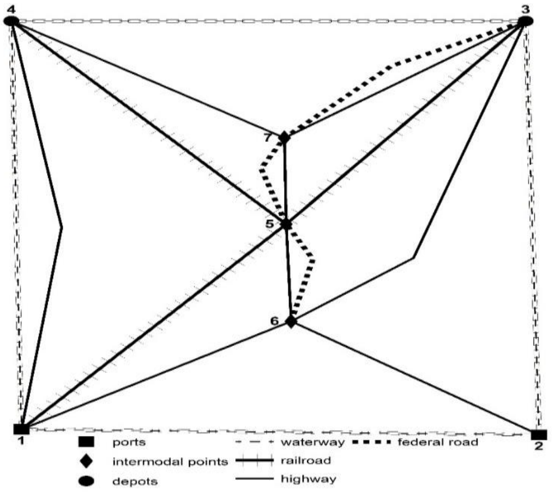

Fig. 2. Transport network.

Table 1 shows the length of arcs between each pair of nodes along with the mode of transportation. In between some pairs of nodes, there are two segments, which indicated accessibility by two modes of transportation. MATLAB software was applied for the analysis by developing the Dijkstra's shortest path algorithm for the intermodal networks. It was used to design the user-interface platform, which enables users to select the origin, destination and objective functions. The user-interface allows inputting data for variables under consideration in order to run multiple analysis and explore trade-offs.

Table 1. Length of arcs in Kilometers (H = highway, F = federal road, W = waterway, R = railroad)

Node		1	2	3	4	5	6	7
1	H				720		150	
	F							
	W		250		740			
	R					300		
2	H						120	
	F							
	W	250		700				
	R							
3	H						600	120
	F							100
	W		700		200			
	R					450		
4	H	720						150
	F							
	W	740		200				
	R					400		
5	H						250	200
	F						300	250
	W							
	R	300		450	400			
6	H	150	120	600		250		
	F					300		
	W							
	R							
7	H			120	150	200		
	F			100		250		
	W							
	R							

In this study, a total number of five-hundred fully loaded containers will be considered. Travel time was estimated based on its relationship with speed and distance as shown in Eq. (1). Highway and federal road are two road classes in this study. In this case, the speed limit for highway and federal road were considered to be 110 km/h and 90 km/h respectively. Similarly, railroad and waterway speed limit were assumed to be 85 km/h and 50 km/h respectively.

$$T_t = \frac{T_d}{S_l} \tag{1}$$

where T_t = travel time (h), T_d = travel distance (km) and S_l = speed limit (km/h).

The carbon dioxide emission (ton.) was calculated based on variables such as emission factor, the weight of the loaded container, number of containers and the distance of the path. In this study, 20-foot dry container was chosen for the analysis. According to container sizes, weight specification of the container includes cargo capacity of 21640 kg and tare weight of 2360 kg [28]. Hence, the total weight of fully loaded container was 24000 kg. The emission factor was obtained from the Greenhouse Gas Protocol (GHG Protocol) and used to estimate the emission for different modes of transport [29]. The indicators are shown in Table 2. The expression for estimation of carbon dioxide emission is as shown Eq. (2).

$$E = \frac{[Ef * Cw * Nc * Td]}{1000} \tag{2}$$

where E = carbon dioxide emission (ton), E_f = emission factor (kg/ton-km), C_w = container weight (ton), N_c = number of containers, and T_d travel distance (km).

Table 2. Associated emission factor for different transport modes.

Freight Transport Mode	**Fuel Emission Conversion Factor (kg/ton-km)**
Road Vehicle **- HGV** **- Articulated** **- Engine size unknown**	0.08869
Train	0.0285
Watercraft **- Shipping** **- Small container vessel (2500 tons deadweight)**	0.02

Generally, there are so many variables that can be considered for transport cost calculation. In this study, the travel cost function was composed of variables such as fuel price, fuel consumption, driver wage and maintenance. Transport cost was calculated using Eq. (3).

$$Tc = [(Fp * Fc * Td) + (Wa * Tt) + (Ma * Td)] * \left[\frac{Nc}{Cv}\right] \tag{3}$$

where T_c, F_p, F_c, and Td are transport cost (Ringgits, RM), fuel price (RM/ litre), and fuel consumption (litre/km), travel distance (km), respectively. Wa, T_t, Ma, N_c, and C_v represent wage (RM/h), travel time (h), maintenance (RM/km), number of containers, and capacity of the vehicle (TEU) respectively. TEU is the twenty-foot equivalent unit and one TEU indicates one unit of the 20-foot ISO-standard intermodal container. The capacity of vehicles was considered based on the number of TEUs that each of them could carry.

4. Results and Discussion

Route selection and modal choice analysis were conducted in pairs of origins and destinations, which are from node one to node three and four as well as from node two to node three and four. In addition, associated trade-offs of different transport modes were evaluated. Node one has been chosen as origin and node three as the destination. There exist twenty-six possible routes from node one to node three as shown in Fig. 3.

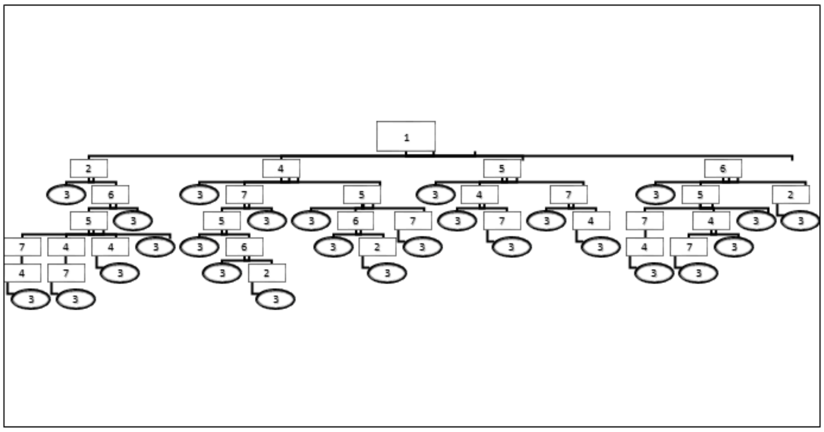

Fig. 3. All possible routes from node 1 to node 3.

4.1. Travel distance analysis

The purpose of travel distance analysis is to determine the least-distance path and transport mode for each segment of the path. The travel distance analysis is only dependent on the length of network segments. The result of travel distance analysis from node one to node three is illustrated in Fig. 4. Route selection analysis result shows that the shortest route was the path of 1-5-7-3 with a total distance of 600 km. This path consists of three segments in which from point one to five covering a distance of 300 km by using the train, from intermodal point five to seven with 200 km by using the highway and finally, from intermodal point seven to the destination point covering a distance of 100 km by using the federal road. Thus, the results of travel distance analysis indicate the combined usage of both train and truck as freight transportation vehicles.

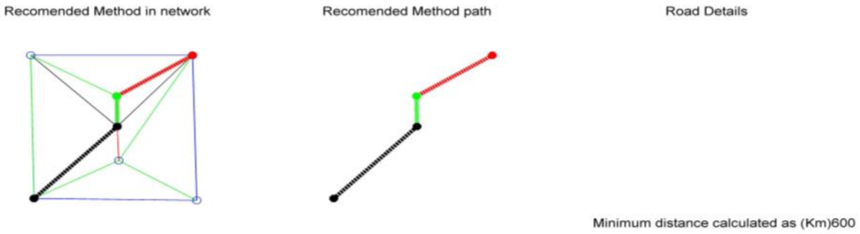

Fig. 4. Travel distance analysis from node 1 to node 3.

4.2. Travel time analysis

Travel time is one of the most crucial factors in freight modal choice. The travel time analysis is dependent on the length of segments and speed limit of each transport mode. The results of travel-time based analysis from node one to node three is depicted in Fig. 5. The results suggested that the least-time path was 1-5-7-3 and its total duration was 6.44 hours. This included railroad mode from node one to node five and highway mode from node five to node seven and from node seven to node three. Road-based, rail-based and waterway-based least-time routes for the same origin and destination yielded 6.55 h, 8.82 h and 18.8 h respectively with the detailed route shown in Figs. 6, 7 and 8. The least-time path was compared with the other three-unimodal transportation modes and the result of this comparison is depicted in Fig. 9. The comparison showed that freight transport by ship is the most time-consuming mode, followed by train and truck. The saving time using least-time intermodal mode (i.e., for train and truck) was approximately 12.36 hours when compared with waterway mode.

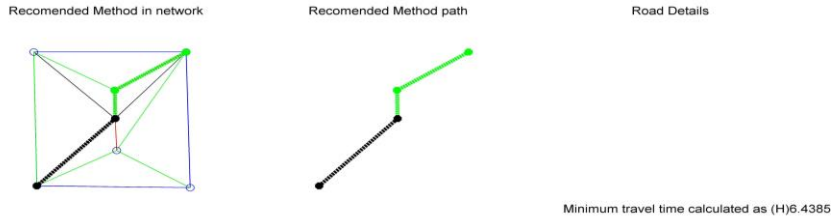

Fig. 5.travel time analysis from node 1 to node 3.

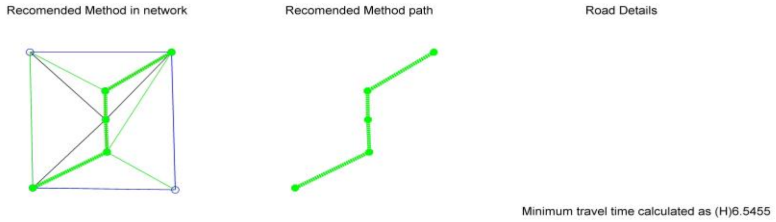

Fig. 6. Road-based travel time analysis.

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Fig. 7. Railroad-based travel time analysis.

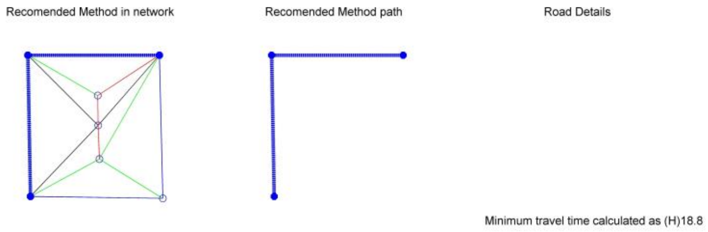


Fig. 8. Waterway-based travel time analysis.

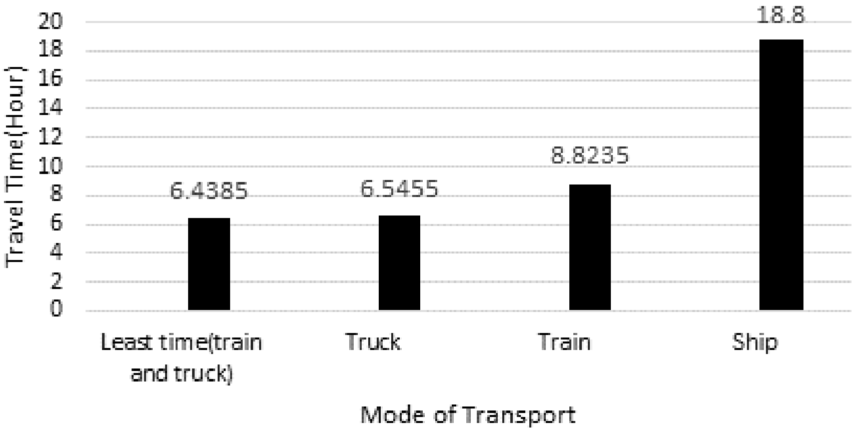


Fig. 9. Travel time comparison from node 1 to node 3.

4.3. Emission analysis

The purpose of emission analysis was to determine the optimum route with least carbon dioxide. Emission analysis dependent on parameters such as a number of containers, the weight of each container, distance and the mode of transport on each edge of the route as described in section 3. A total number of five-hundred fully loaded containers was chosen for the emission analysis from node one to node three. Based on the aforementioned assumptions, the emission analysis was conducted and its result is as shown in Fig. 10. The results showed that the least-emission route was the path of 1-4-3 by using waterway mode for both segments with total carbon dioxide of 225.6 ton. The results of road-based and railroad-based emission analysis are shown in Figs. 11 and 12 respectively. Figure 13 shows the carbon dioxide comparison among the waterway mode (least-emission mode), road-based and railroad-based least-emission results. This means that movement of freight by ship emits almost 520-ton carbon dioxide less than the road mode and about 30 ton less than railroad mode.

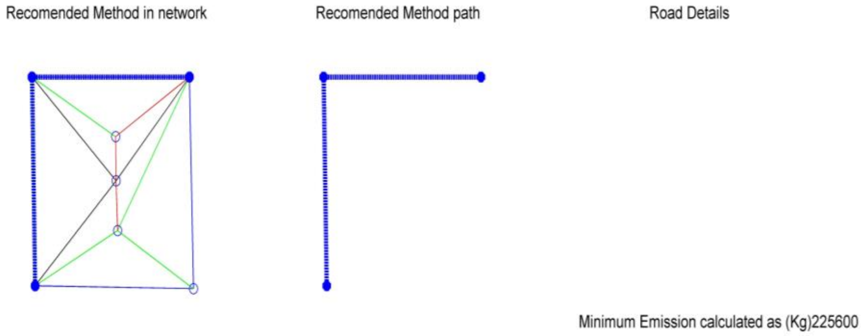


Fig. 10. Emission analysis.

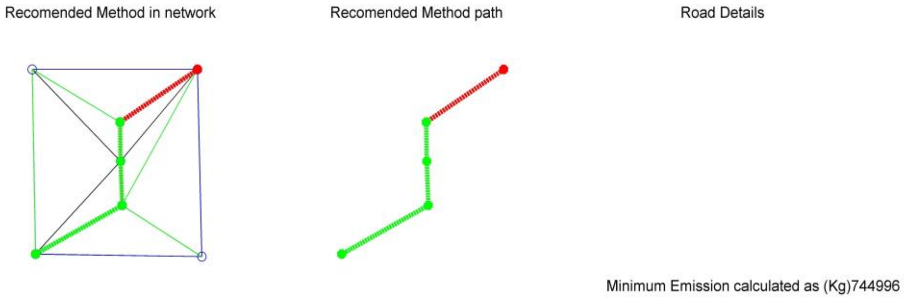


Fig. 11. Road-based emission analysis.

Fig. 12. Railroad-based emission analysis.

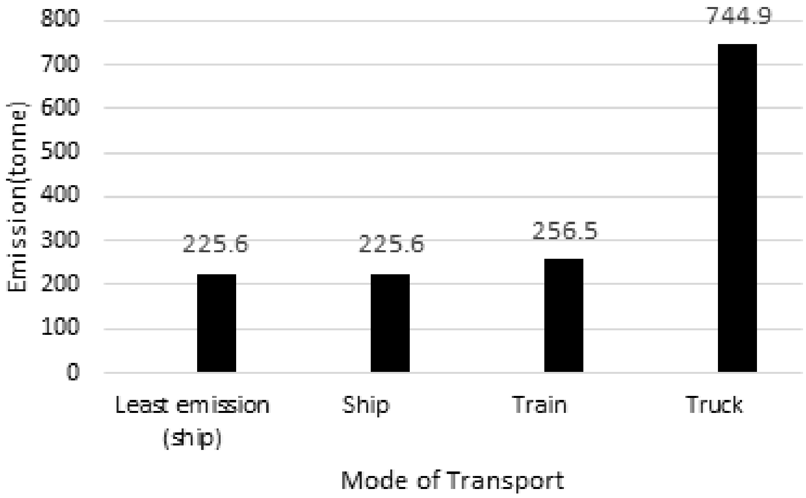


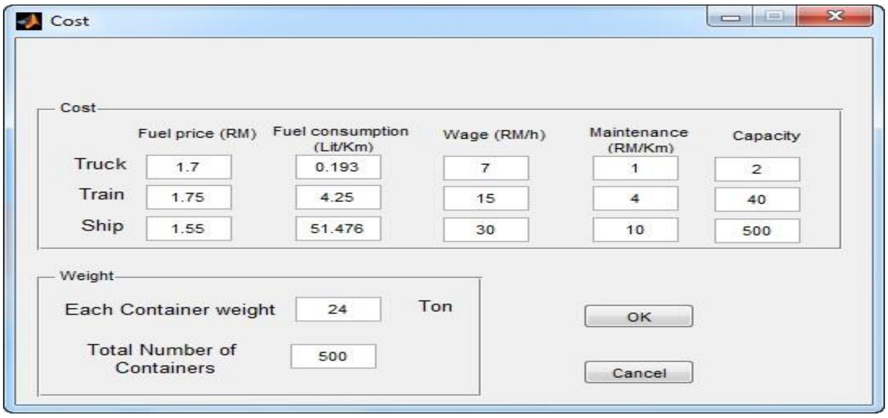
Fig. 13. Emission comparison from node 1 to node 3.

4.4. Travel cost analysis

Cost analysis is intended to identify the optimum path and mode of transport with the least possible cost for shipment of containers from source to the destination. Travel cost analysis is affected by a variety of parameters such as fuel price, fuel consumption, travel distance, driver wage, travel time, maintenance cost, the number of containers, and capacity of the vehicle. Just like the case of carbon dioxide emission analysis with five-hundred 20-foot dry containers. Considering prevailing diesel prices for the truck, train and ship as 1.7, 1.75 and 1.55 RM per litre, respectively. According to Cenek et al. [30], fuel consumption for the truck, train and ship are approximately 0.19, 4.3 and 51.48 litres per kilometre, respectively.

Driver's wage was assumed to be on an hourly basis and it varies for different modes of transport. Maintenance cost of transport vehicles is considered per kilometre of travel. The assumed capacity of the truck, train and ship were 2, 40 and 500 TEUs per vehicle respectively. These parameters were input into the analysis via user-interface for calculation of cost as depicted in Fig. 14. The result of cost analysis for the movement of containers from node one to node three is as depicted in Fig. 15. The least-cost path from node one to four and from node four to three in which the mode of transport for both segments is a ship. The total estimated cost for this path is RM 84964.53.

The results of the cost analysis for identification of least-cost route based on the road and railroad mode are illustrated in Figs. 16 and 17 respectively. Figure 18 shows the comparison of related cost among ship (least-cost mode) and least-cost routes based on road and railroad. The comparison indicated that the most expensive mode was road mode and it is followed by railroad and waterway modes. The cost for shipment using truck was approximately three times of that of the ship (Fig. 18).



Cost

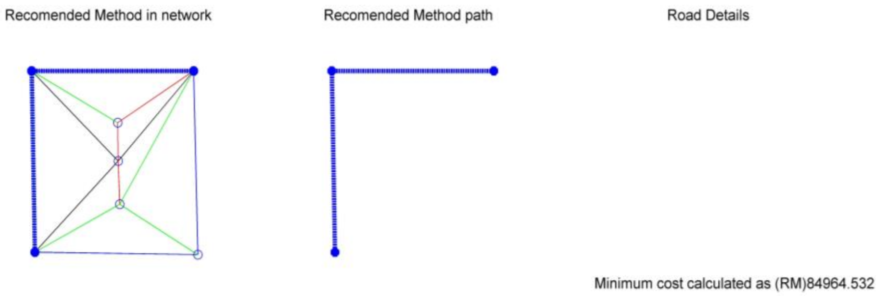
	Fuel price (RM)	Fuel consumption (Lit/Km)	Wage (RM/h)	Maintenance (RM/Km)	Capacity
Truck	1.7	0.193	7	1	2
Train	1.75	4.25	15	4	40
Ship	1.55	51.476	30	10	500

Weight

Each Container weight: 24 Ton

Total Number of Containers: 500

Fig. 14. Assumptions for the cost analysis.



Minimum cost calculated as (RM)84964.532

Fig. 15. Travel cost analysis from node 1 to node 3.

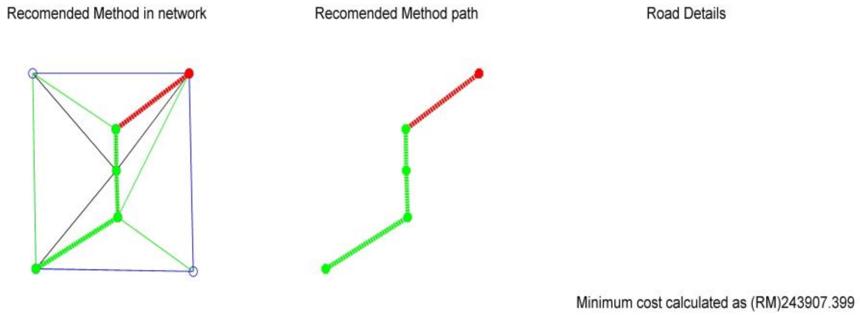


Fig. 16. Road-based cost analysis.

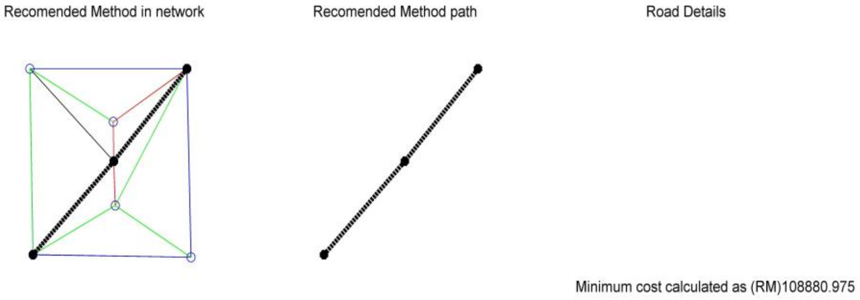


Fig. 17. Railroad-based cost analysis.

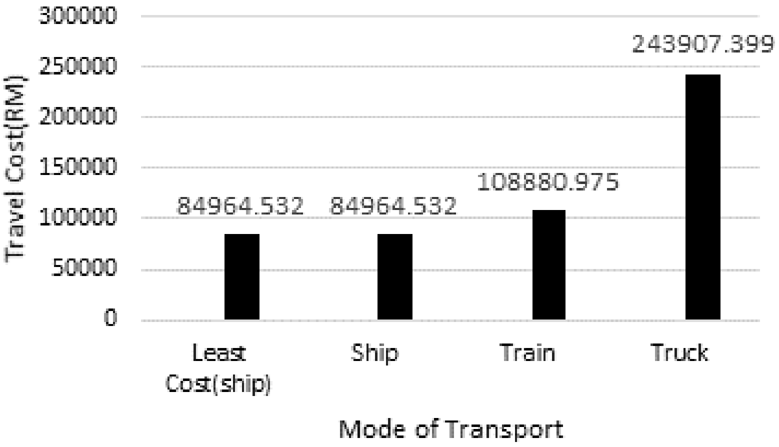


Fig. 18. Travel cost comparison from node 1 to node 3.

Table 3 shows the result of route selection and modal choice analysis for the four different decision objectives of least distance, least time, least emission and least cost from node no. 1 to node no. 3. The trade-offs between least time and least-emission routes can be identified if their associated routes are compared. The comparison between them clearly indicated that although travel time of least-emission route was approximately three times of least-time route, its carbon dioxide emission was almost half. Based on the result, the least-cost route was same as least-emission route and the cost differential between the least-cost path and least time was RM 69926.76. The combination of train and truck was the best modal choice for minimum distance and minimum travel time objectives, while the ship was the best vehicle when least emission and least cost were objectives.

The same procedures for the previous analysis were adopted for other three different pairs of origins and destinations, which are from node no. 1 to node no. 4, from node no. 2 to node no. 3 and from node no. 2 to node no. 4. The results of the analysis for these routes are shown in Tables 4, 5 and 6. Based on the results in Table 4, the waterway was preferred transportation mode for the least emission and least cost purposes, while a shipment-using truck can be the fastest mode. Comparing the least-distance route with least-time route indicates that firstly, the journey of least-distance route take longer time than the least-time route although its distance was 70 km less.

Secondly, the cost and carbon dioxide emission of the least-distance route was less. Since the results of least-emission and least-cost routes are the same, there are no trade-offs between these two routes. The cost of the least-time route was three times of that of the least-cost path and its carbon dioxide emission was higher for about four times, but its travel time was about 8 hours less. The detailed results for the network analysis for the routes from node 2 to node 3 and node 2 to node 4 are as shown in Tables 5 and 6.

Table 3. Result of the network analysis from node 1 to node 3.

	Cost (RM)	**CO_2 (ton)**	**Time (hour)**	**Distance (km)**	**Direction**
Minimum Distance	148286.13	421.84	6.44	**600**	1-5-7-3 (railroad & highway & federal)
Minimum Time	154891.29	443.16	**6.43**	620	1-5-7-3 (railroad & highway)
Minimum CO_2	84964.53	**225.6**	18.8	940	1-4-3 (waterway)
Minimum Cost	**84964.53**	225.6	18.8	940	1-4-3 (waterway)

Table 4. Result of the network analysis from node 1 to node 4.

	Cost (RM)	**CO (ton)**	**Time (hour)**	**Distance (km)**	**Direction**
Minimum Distance	165329.31	475.09	177.6	**650**	1-5-7-4 (railroad & highway)
Minimum Time	250512.52	766.28	**6.54**	720	1-4 (highway)
Minimum CO_2	66886.97	**177.6**	14.8	740	1-4 (waterway)
Minimum Cost	**66886.97**	177.6	14.8	740	1-4 (waterway)

Table 5. Result of the network analysis from node 2 to node 3.

	Cost (RM)	CO_2 (ton)	Time (hour)	Distance (km)	Direction
Minimum Distance	233469.37	713.06	6.29	**670**	2-6-5-7-3 (highway & federal)
Minimum Time	240074.5	734.35	**6.27**	690	2-6-5-7- 3 (highway)
Minimum CO_2	63271.46	**168**	14	700	2-3 (waterway)
Minimum Cost	**63271.46**	168	14	700	2-3 (waterway)

Table 6. Result of the network analysis from node 2 to node 4.

	Cost (RM)	CO_2 (ton)	Time (hour)	Distance (km)	Direction
Minimum Distance	250512.52	766.28	6.54	**720**	2-6-5-7-4 (highway)
Minimum Time	250512.52	766.28	**6.54**	720	2-6-5-7-4 (highway)
Minimum CO_2	81349.02	**216**	18	900	2-3-4 (waterway)
Minimum Cost	**81349.02**	216	18	900	2-3-4 (waterway)

5. Conclusion

This paper presents the effective approach to the development and analysis of hypothetical intermodal freight transport network for the route selection, modal choice analysis and trade-offs evaluation associated with different modes of freight transportation. In this paper, the MATLAB-based model was applied to identify an optimum path in intermodal freight transport network and ArcMap to build the intermodal transport network. The proposed approach was to determine the most preferred path and modes of transport for four (4) cases of origin-destination pairs. Travel distance, travel time, carbon dioxide emission and travel cost were considered as decision objectives. In addition, different modes of freight transportation and their combinations were compared for the movement of a certain number of containers according to mentioned objective functions.

The results of network analysis showed that the combination of road and railway was the least-time route from node one to three, while in other three cases, only road mode was the least-time route. Therefore, the road was the fastest method of freight transportation in most cases. In contrast, the ship was found to be the slowest mode. Container movement by ship takes time at least two times longer than other transport modes. Furthermore, the waterway has the least emission among the investigated modes of transport and their combinations. The comparison of emitted carbon dioxide showed that ship was more environmentally friendly with the least emission, followed by train and truck. In terms of cost, the ship was the most cost-effective mode of freight transportation followed by train and truck. This approach can be adopted for the analysis of larger and real intermodal networks taking into account the modal change time, emission and cost at intermodal points.

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