Logistic Strategy to Face Disruption in Freight Multimodal Transportation Network

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Abstract

This paper investigates distribution strategies when facing disruption. This strategy is based on the flexibility in transportation planning through the use of multimodal transportation. The flexibility mode of transportation mode will make it easier to re-plan routes when the system is affected by disruption but usually needs a higher total cost. The development of this model is based on the determining of the delivery route that results in the least total cost and time. The calculation result is intended to compare modes used in either single mode or modal combination in terms of cost and time used.

Keywords
Logistic, Routing, Disruptions, Multimodal, Flexibility.

1. Introduction

In a transportation system, the types of disruptions include natural disaster, transportation infrastructure breakdown, accidents, congestion, bridge breakdown, etc. some disruptions are kind a rare event but have a large impact in systems, for example, the economic impact that affected the transportation facilities users. Ishfaq (2012) provides an example of the impact of transportation disruption which includes; the earthquake in California which caused enormous financial losses in the business sector due to damaged transportation facilities. Beside that, Wilson (2007) in Ishfaq (2012) writes that countries in the Pacific Rim are also affected by the supply chain of electronic and automotive products from earthquakes and tsunamis. In addition, Indonesia has a high various transportation disruption with more risk variety; congestion, accidents, natural disaster, extreme weather, etc. Apart from that disruptions, natural disasters are the highest potential disruptions accidents due to Indonesia's geographical position which located on the bound of the active Eurasian and Australian plates.

The impact of transportation disruption is demand cannot be fulfilled according to the agreement and the total cost tended to increase. When disruptions occur in the transportation network, one of best strategy is to determine alternative routes and mitigate the negative impacts of these disruptions to maintain logistical performance. Research on transportation disruption developed from 1990 to the present (Burgholzer *et al.*, 2013a). The development of the research is to follow the developed research on transportation models, ranging from unimodal transportation to multimodal transportation. Some paper that considers disruptions in single mode includes; Narayanaswami and Rangaraj (2013); Gedik *et al.* (2014); Zilko et al., (2016) and Uddin *et al*, (2017) analyzed in rail network, Liu et al., (2016), Di et al., (2013) and Wong et al., (2015) investigated in ship network and Udenta *et al.*, (2013) studied in road network. While, the researcher that investigated multimodal transportation network with considering disruptions is; Miller-hooks et al., (2012), Huang et al., (2011), Pant et al, (2015), Ishfaq, (2012), Uddin and Huynh, (2016a) and (Zeng et al., 2013). Besides that, the disruptions had a natural characteristic, anticipated and unanticipated disruptions. For anticipated disruptions include customer disruptions, transportation infrastructure improvement, and others. Whereas unanticipated disruptions include natural disasters, accidents, and others. For the anticipated disruptions, the model parameter came from the disruption's variable. For example, demand changing, location changing and time window changing. In another side, the unanticipated disruptions the parameter model include the time variable or delay or others. Some strategies used to overcome this problem include determining alternative routes, alternative modes, depots and scheduling the departure schedule (Rosyida et al., 2018). Ishfaq, (2012) analyzes alternative routes when facing disruptions. The objective is to minimize the additional costs in the system. Some studies also develop strategies for determining the most optimal alternative routes when facing disruptions (Narayanaswami and Rangaraj, 2013); (Gedik *et al.*, 2014), (Zilko, Kurowicka and Goverde, 2016); (Huang, Hu and Zhang, 2011); (Uddin and Huynh, 2016b); (Miller-hooks, 2011); (Burgholzer *et al.*, 2013b); (Morlok and Chang, 2004) dan (Snyder and Daskin, 2005). The alternative route is sought one of them through a strategy of flexibility and efficiency. These strategies were opposite each other or weaken each other. When disruptions occur in the system, the flexibility strategy will affect the level of efficiency. In another side, if we choose the efficiency strategy, the level of flexibility will be decreased. So, it is sought to optimize the rate of decrease in efficiency when disruption occurs (Ishfaq, 2012). Ishfaq, (2012) investigated an alternative route on multimodal transportation use shortest path problem approach. Ishfaq only considered the effect of disruptions on the delay scenario and Ishfaq did not explain the detail types of disruptions. Some other publications analyze optimal route search by considering disruption explicitly on links, nodes and networks (Uddin and Huynh, 2016a), the type of recovery strategy scenario that is carried out has an impact on increasing vehicle volume (Miller-hooks, Zhang and Faturechi, 2012), disruption which affects the average speed of the vehicle (Rosyida et al., (2018) and customer disruptions (Wang et al., 2012).

There are still need to investigate disruptions in a multimodal transportations research area. Some papers tended to investigated about the impact of disruptions in time but not investigated the time changing reason. In addition, there are also still few papers discussing disruption that have an impact on decreasing vehicle speed in the scope of multimodal transportation. On the other hand, in the multimodal transportation model, synchronizing schedules are very important. This problem was developed by Behdani *et al.*, (2016). So, in this study, a route planning model will be developed on a disrupted systems model. The disruptions are affecting the decline in vehicle speed average. The objective of the model is to search the optimal solutions when the disruptions occurred in the system (unimode or multimodal).

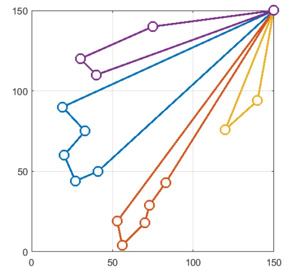
2. Problem Description

This study, discussing tactics planning on multimodal transportation networks, namely the choice of modes and routes. The development of these planning problems began to develop from being only effective and efficient to be more effective, efficient, flexible and resilient. These conditions need to develop because there are still possibility of disruption that occurs in the system. Disruptions source, humans or nature, affect the network system delivery performance. The Decreasing network performance impacted the transportation time and cost.

To deal with these uncertainties, one kind of flexibility strategy in transportation planning is mode flexibility. The combination of modes (multimodal) provided a route combination choices. So, when there is a disruption on an edge, it can be diverted to another route. In this study, two types of mode choices were considered, namely, trucks and ships. Both terminals connected by sea lanes and between terminals, depot, and customer connected by highway lanes. This combination is used as an alternative route choice to fulfill the demand.

Figure 1 illustrates the multimodal and unimodal supply networks. For the unimodal supply network, the node consists of a depot and customers. While, for multimodal supply network, the node consists of a depot, ports, and customers. Alternative shipping lines are the process of shipping by road only or a combination of road and sea.

The analyzed disruption is disruption which has an impact on the decrease in the average speed of the vehicle. Rosyida et al, (2018) states that the need to consider disrupting analysis has an impact on decreasing vehicle speed on multimodal transportation. Testing is done to find out more optimally where the use of multimodal and unimodal transportation. In this case, the disruption scenario analyzed for the impact of route selection using unimodal or multimodal.



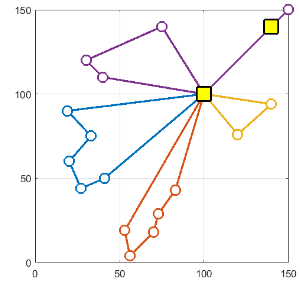


Figure 1. 1a. Unimoda Supply Network. 1b. Multimoda Supply Network

In addition, a multimodal strategy creates additional time in transportation. Additional costs incurred include transportation costs, transfer fees and hospitalization fees (waiting) because they come too early from the scheduled schedule and are due to be late. While, for the additional time is coming from transportation time, transfer time and waiting time for the consequences to arrive too early or because it arrives too late from a predetermined schedule. When disruptions occur in the system, the flexibility strategy will affect the level of efficiency. The flexibility and efficiency strategy are optional choice. When the objective is time, efficiency strategy is suitable. In another side, if we choose the cost saving, the flexibility strategy is the best. When there is a disruption in the system, the level of efficiency will decrease because the level of flexibility is increased, so that in this model it is sought to optimize the rate of decrease in efficiency when disruption occurs through the selection of the most minimal total costs generated. So that in this case, it will also be done. Loss analysis and the advantages of unimodal and multimodal use without disruption or using disruption.

3. Mathematical Model

3.1. Notation

Table 1. Model Notation

Notations	Meanings
N	Customer and port index, N= {1, 2, n}
N_o	Depot, port and Customer index, $N_0 = \{0\} \cup N$
K	The number of containers
M	Mode index, m={1,2}, 1=truck; 2=ship
θ_j	The transfer cost in node j
q_{ijkm}	The available load of container k at mode m between node i and j
Q	The maximum Capacity each container
EW_{ijkm}	The waiting time caused by the earliness of container k of mode m from node i to j that arrives at destination node j before its opening time
LW_{ijkm}	The waiting time caused by the lateness of container k of mode m from node i to j that arrives at destination node j before its closing time.
ws_{ijkm}	Waiting cost in node j
To_n^j	The opening time of node j on period n
TA_{jk}	The arrival time of container k on node j
Tc_n^j	The closing time of node j on period n
TA_{ik}	The arrival time of container k on node i
τ_{jk}	The transfer time of container k on node j
c_{ijkm}	The cost between node i and j of container k with mode m, $i, j \in N_0$
t_{ijkm}	The travel time between node i and j of container k with mode m, $i, j \in N_0$
d_i	The amount of demand at node i, $d_0; d_1; d_2 = 0$
s_i	The service time at node i
x_{ijkm}	A binary variable. $x_{ijkm} = 1$, when container k at mode m travel from node i to j, otherwise x_{ijkm}=0
δ_j	A binary variable. $\delta_j = 1$, when there is transfer process in node j, otherwise $\delta_j = 0$

U_{ik}	A binary variable. U_{ik} = 1, when node i visited by vehicle k, otherwise U_{ik}=0
P_{ijkm}	A binary variable. P_{ijkm} = 1, if there is lateness of container k travel from node i to j using mode m at destination j, otherwise P_{ijkm}=0
Sta_i	starting service time pada node i
$[o_i, cls_i]$	time window at node i, o_i, earliest service time; end_i, latest service time
M	big positive number

3.2. Model Formulation

$$minimasi \sum_{(i,j)\in N_o,k\in K,m\in M} c_{ijkm}X_{ijkm} + \sum_{j\in N,k\in K} \delta_{jk}\,\theta_{jk} + \sum_{(i,j)\in N_o,k\in K,m\in M} EW_{ijkm}\, ws_{ijkm} + \sum_{j\in N,k\in K} LW_{ijkm}\, ws_{ijkm} \quad (1)$$

$$\sum_{k\in K} U_{ikm} = 1 \qquad \text{for each } i \in N \text{ dan } \delta_j \quad (2)$$

$$\sum_{k=1}^{K}\sum_{j=2}^{N} X_{1jk} = \sum_{k=1}^{K}\sum_{i=2}^{N} X_{i1k} \leq K \quad (3)$$

$$\sum_{l-0,l\neq i}^{N} X_{likm} = \sum_{j-0,j\neq i}^{N} X_{ijkm} = U_{ikm} \quad (4)$$

$$\delta_j \geq \sum_{i\in N} X_{ijkm} - \sum_{i\in N} X_{jikm} \qquad \forall k \in K, j \in N, m \in M \quad (5)$$

$$q_{ijkm} \text{ x } X_{ijkm} \leq Q \qquad i,j \in N, k \in \{1,\ldots\ldots,k\}, m \in \{1,\ldots\ldots,m\} \quad (6)$$

$$\sum_{i=1}^{N_0} d_i \text{ x } U_{ikm} \leq Q \qquad k \in \{1,\ldots\ldots,k\}, m \in \{1,\ldots\ldots,m\} \quad (7)$$

$$To_n^j \leq TA_{jk} \leq Tc_n^j \quad (8)$$

$$TA_{jk} \geq TA_{ik} + \tau_{jk} + t_{ijkm} - \left(1 - X_{ijkm}\right)M \quad (9)$$

$$EW_{ijkm} \geq To_n^j - TA_{jk} \quad (10)$$

$$LW_{ijkm} \geq To_{n+1}^j P_{ijkm} - TA_{jk} \quad (11)$$

$$Tc_n^j - TA_{jk} + MP_{ijkm} \geq 0 \quad (12)$$

$$Tc_{n+1}^j \geq TA_{jk} \quad (13)$$

$$X_{ijkm} = \{0,1\} \qquad i,j \in N_0, k \in \{1,\ldots\ldots,k\}, m \in \{1,\ldots\ldots,m\} \quad (14)$$

$$U_{ikm} = \{0,1\} \qquad i \in N_0, k \in \{1,\ldots\ldots,k\}, m \in \{1,\ldots\ldots,m\} \quad (15)$$

$$\delta_j = \{0,1\} \qquad \forall_j \in N \quad (16)$$

$$EW_{ijkm} \geq 0 \quad (17)$$

$$LW_{ijkm} \geq 0 \quad (18)$$

The model objective (1) is to minimize total delivery cost; transportation cost, transfer cost, waiting cost. Constraint (2) states that every consumer will only be served once and constraint (3) states that every vehicle departing from the depot cannot be more than the number of vehicles in the depot. In addition, constraint (4) states every vehicle that enters from node i must be out from node i as well. Constraint (5) states that a node is port or not. Constraint (6) and (7) states maximum limitation of loading of every container and constraint (8) – (13) is time windows constraint in port while, constraint (13); (14); (15); (16); (17) and (18) explains the value and range of X_{ijkm}; U_{ikm}; δ_j; EW_{ijkm} dan LW_{ijkm}..

4. Computational Experiment

Numerical experiments were carried out to analyze the problems of vehicle route in unimodal or multimodal case. The modes considered are trucks and ships. The transportation system network consists of 18 nodes: one depot, two ports, and 15 customers. The depot has four vehicles with a total capacity of 6.5 each. The distance between nodes was measured from the coordinate of each node. The details of the data are presented in table 2. The speed of each mode; truck and ship and the transportation cost, transfer cost, and waiting penalty cost figured in table 3.

Table 2. The Node Coordinate and The Customer Demand Data

Node	X	Y	Demand
(1)Depot	150	150	-
(2)Port 1	148	148	-
(3)Port 2	100	100	-
(4)Customer 1	19	90	1
(5)Customer 2	33	75	1.8
(6)Customer 3	20	60	1.1
(7)Customer 4	53	19	0.6
(8)Customer 5	140	94	1.9
(9)Customer 6	27	44	1.4
(10) Customer 7	75	140	1.2
(11) Customer 8	56	4	0.2
(12) Customer 9	30	120	1.7
(13) Customer 10	120	76	0.8
(14) Customer 11	41	50	0.9
(15) Customer 12	83	43	0.8
(16) Customer 13	40	110	1.9
(17) Customer 14	73	29	1.6
(18) Customer 15	70	18	0.9

Table 3. The Average Speed and Cost of Different Modes of Transport

Node	Speed (Km/H)	Transport Cost ($/Km)	Transfer Cost ($)		Transfer Time (H)		Waiting Penalty ($)
			Truck	Ship	Truck	Ship	
Truck	60	1	-	30	-	3	-
Ship	37	0.37	30	-	18	-	80

Numerical calculations are designed in two scenarios; unimodal and multimodal. The total cost of every scenario compared in two conditions; under disruption and without disruption. The comparison aims to know the best scenario when face disruption. The disruption considered is based on the results of a study by (Rosyida et al., 2018) which states that the strategy to change routes when there is disruption is when the average vehicle speed on the highway reaches 7 km/hour. It is used as a reference to determine the disruption scenario tested in this case study. The results of the numerical calculations obtained are presented in table 3.

Numerical experimental results show that unimodal use will provide a greater total cost than multimodal. But the total time needed to deliver is faster than the multimodal one. This happens even though there is no disruption in the shipping lane. When disruption occurs on the shipping lane on the highway, the total cost becomes higher.

Table 4. Numerical Experiment Result

Scenario		Without Disruption			With Disruptions Total Cost		
		Best Route	**Total Cost**	**Transportation Time Average/Container**	**Best Route**	**Total Cost**	**Transportation Time Average/Container**
(Unimoda)	60	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$15,754.08	187.55	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$15,754.08	187.55
	50	-	-	-	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$15,813.43	188.25
	45	-	-	-	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$15,853.02	188.73
	37	-	-	-	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$15,938.62	189.75
	26	-	-	-	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$16,142.34	192.17
	24	-	-	-	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$16,199.45	192.85
	16	-	-	-	0-11-6-3-2-1-0;0-12-14-15-8-4-0;0-10-5-0;0-7-9-13-0	$16,570.62	197.3
	7	-	-	-	0-10-6-3-2-0;0-12-14-4-11-1-0;0-9-5-8-15-0;0-7-13-0	17,436.3	207.3131
	3	-	-	-	0-10-6-3-2-0;0-12-14-4-11-1-0;0-9-5-8-15-0;0-7-13-0	17,436.3	207.3131
	0	-	-	-	0-10-6-3-2-0;0-12-14-4-11-1-0;0-9-5-8-15-0;0-7-13-0	17,436.3	207.3131
(Multimoda)	60	0-1-2-13-8-5-4-3-2;0-1-2-14-16-17-10-6-2;0-1-2-12-7-2;0-1-2-9-11-15-2	$14,484.56	540.48	-	-	-

5. Conclusion

This paper discusses the logistics strategy (routing) that should be taken when disruption occurs. The utilization of modal flexibility will have an impact on the total time produced longer than those using only one mode because there are several additional processes in it. However, the costs incurred are more minimal. Moreover, when there is disruption on the highway lane, there is a possibility that the total costs incurred are also higher. So in this case, when there is a disruption in the highway, a multimodal strategy is the best strategy that produces the most minimal total costs. But when the decision maker in making a decision is based on the total time needed for the delivery process, the unimodal strategy still results in a lower total time compared to the multimodal.

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