Proceedings Paper:

Hidayati, LNN, de Jong, G orcid.org/0000-0003-3405-6523, Whiteing, A orcid.org/0000-0003-3480-1255 et al. (1 more author) (2022) A Probabilistic Model of Container Port Demand in Java Concerning the Port Hinterland Connectivity. In: Lecture Notes in Civil Engineering. 15th International Conference on Rehabilitation and Maintenance in Civil Engineering, 08-09 Jul 2021, Surakarta, Indonesia. Springer , pp. 781-789. ISBN 9789811693472

https://doi.org/10.1007/978-981-16-9348-9_69

A Probabilistic Model of Container Port Demand in Java Concerning the Port Hinterland Connectivity

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Abstract. The port demand could be modelled from the port choice of the ports' actors. From the actors' perspectives, factors influencing port choice do not solely depend on the port performance itself. As a port is an interchange location of land and sea transport, the port selection is closely associated with the inland mode choice. This study applies a multinomial logit (MNL) model to predict the probability of a joint port and inland mode choice in Java, Indonesia. Six factors classified into port performance and port hinterland connectivity are applied to estimate the probability of port demand. The model also allows us to estimates the port hinterland boundaries as a corollary of port choice made by the actors. Further from the simulation on several transport strategies, introducing Patimban port as a new container port in Java greatly affects the adjacent port demand. Reducing rail transport time and improving port performance also leads to substantial port and mode shifting for container transport in Java.

Keywords: MNL model, Port choice, Inland mode choice, Port hinterland connectivity.

1 Introduction

This paper presents a study on forecasting probability of container port demand using a discrete choice model. The demand of a port could be estimated through the choice of port made by the ports' actors (e.g., shippers and carriers), in which their loyalty in choosing the port depends on many factors. In this paper, six variables classified into two main categories, port-hinterland connection, and port performance, are examined. The model simulation results can be used for predicting the port hinterland boundaries and predict the demand volatility of port and inland mode if particular transport strategies are applied.

Port hinterland connectivity provides port authorities information about factors that may affect their port market share. Wang et al. (2016) argue that efficiently managing transport connectivity of the port and its hinterland areas could build customer devotion and potentially attracting more customers hence expand the port market share [1]. For example, Nugroho et al.(2016) demonstrated that a reduction of 20% in hinterland mode time could raise port market share by 2% [2]. Secondly, Wang et al. stated that the merit of analyzing port hinterland is to identify competitiveness with surrounding ports, thus knowing the major port rivals or opening up a chance to collaborate with other ports to develop transport strategies to guarantee port sustainability [3].

A surge of research effort has been directed to utilize discrete choice models to analyze port choice. Malchow and Kanafani [4] discussed applying the logit-based disaggregate model to predict choice made by shipper over the route and port choices. Zondag et al. [5] demonstrate the MNL model to estimate the probability of using a specific transport logistics chain which included port within the transport chain determined by carriers. Tang et al. [6] offered an approach to improve the MNL model's use to predict shipping companies' port choice by integrating a transport network attributes into the choice explanatory variables. Tapia et al. [7] perform an advanced discrete choice model, a Multiple Discrete Extreme Value Model (MDCEV), to estimate the mode and port choice in Argentina and further use the model to evaluate impact of rail transport investment.

The model discussed in this paper is the multinomial logit (MNL) model on port and inland mode choice. This model combines both the port choice and inland mode choice into one choice alternative and examines the actor decision over the possible alternatives. Nugroho et al. [2] stated that not many literatures investigated these merged choices compared to abundance of literature analyzing the choices separately. Port is a midway interchange hub connecting land and sea transport; further, joint estimation of port and inland mode seems complicated. It may generate a massive number of possible alternatives that create difficulties in data collection. Thus, some studies either estimate port choice mode choice separately or treat port choice as part of intermodal transport routes to transport goods from origin to final destination location [4, 5, 8]. Applying the joint method, particularly for Java island, Indonesia, is possible as there are only three major container ports. Moreover, by this joint choice model, the impact of managing port hinterland connectivity to port demand could be identified. In the model, factors affecting port and inland mode choice categories as port performance variables are port cost and port ship calls. On the other hand, inland transport cost, transport time, reliability and GHG emission are the relevant variables for the port hinterland connection.

The rest of this paper is arranged as follows. The following section elaborates on the modelling framework applied. It starts with the intermodal transport builder to generate the value of explanatory variables of port hinterland connectivity and then continues with the MNL model's explanation. The third section summarizes the model application, and the final conclusions are in section four.

2 Modelling Framework

2.1 Intermodal Transport Builder

We begin this section by introducing the model of an intermodal transportation network in Indonesia, which we will denote as the transport chain builder (TC builder), to generate the explanatory values for the variables of port hinterland connectivity (i.e., inland mode cost, time, and GHG emission). The TC builder model portrays the interaction between transportation network and possible transport chain[1] combinations and the level of service connecting origin and destination location. In the TC builder, a node could represent a TC zone (i.e., the centroid of a group of subdistrict areas), transport terminal, and road junction. The link acts as a connector between nodes that depict the road, railways, sea routes, and flight routes. For this paper, only road and rail transport network within Java considered.

The mode characteristics applied in TC builder are provided in Table 1. The transport cost function used here is derived from the cost function applied in Zukhruf et al. [9], while the speed values are obtained from the data of the ministry of transport and Nugroho [10]. The transport chain's determination for only truck mode and truck-train mode combination follows the shortest path algorithm based on the total transport cost. From this path, then the total transport time and total GHG emission will be calculated. Apart from the mode cost function and speed variable, the total transport cost and total transport time also consider the handling cost and waiting time at the mode interchange location (i.e., railway station/terminal).

Table 1. Mode characteristics.

Mode	Cost function (Rp/TEU per km)[2]	Time function (hour)[3]	Emission function ($KgCO_2e$)
Truck	distance*846.96*11.6	distance/37.00	distance*62*11.6
Rail	distance*686.33*11.6	distance/36.24	distance*22*11.6

2.2 Probabilistic Model in Port and Inland Mode Choice in Java

Probabilistic model using discrete choice modelling usually roots on observed behavioral data that better reflect the reality of decision-making. An individual (in this case a shipper or exporter firm) chooses the alternative based on its attractiveness, characterized by a utility (V_{pm}), in comparison to other alternatives. In this paper, the utility of

[1] A transport chain defines as a sequence of modes employed in the process of shipping goods from the point of origin to the destination location.

[2] In this paper, the cost value of the TC builder will be converted into TEU/Ton by multiply the initial value of 1 TEU = 11.6 Ton.

[3] Time function is the calculation of distance divided by speed in km/hour.

each alternative is derived from the research performed in Nugroho [10] which estimates its model based on the stated preference data. The utility function of port and inland mode choice in Java can be expressed by Eq. (1).

$$V_{pm} = ASC_{pm} - 0.257(PC_p) - 0.817(PSC_p) + 1.93(IMC_{opm}) - 0.863(IMT_{opm}) - 0.406(IMR_{opm}) + 0.683(IMG_{opm}) \tag{1}$$

V_{pm} The observed utility of the alternative p using mode m
ASC_{pm} Alternative specific constant for alternative port p using inland mode m
PC_p Port cost for 1 TEU in port p (thousand Rp)
PSC_p Ship calls of international container vessel per week in port p
IMC_{opm} Inland mode cost for transporting 1 TEU FCL from origin o to port p using inland mode m (thousand Rp)
IMT_{opm} Inland mode time for transporting 1 TEU FCL from origin o to port p using inland mode m (hours)
IMR_{opm} Inland mode reliability for transporting 1 TEU FCL from origin o to port p using inland mode m (%)
IMG_{opm} Inland mode GHG emission for transporting 1 TEU FCL container from origin o to port p using inland mode m (Kg CO_2e)

As inferred from Eq. (1), the alternative i defined as alternative choosing port p using inland mode m, consequently the choice probability of alternative i for individual n, for a Multinomial Logit (MNL) model (P_{in}) can be calculated as in Eq. (2):

$$P_{in} = \frac{e^{V_{in}}}{\sum_{j=1}^{J} e^{V_{jn}}} \tag{2}$$

3 A Case Study

In a case study of port hinterland connectivity in Java island, the proposed models will be used to calculate the probability of port and inland mode choice from surrounding zones. Java island has three main container port: Tanjung Priok, Tanjung Emas, and Tanjung Perak, which hold about 60% of total container transport in Indonesia [8]. In an attempt to meet the growth of container transport, the government has a plan to build the biggest container Port in Java, namely Patimban Port. This port expected to support the container traffic existing in Tanjung Priok port which currently faces a capacity problem and reduces the logistics cost due to its strategic location in between industrial areas of Bekasi, Karawang, and Purwakarta [2]. Referring to the Eq. (1) and Eq. (2), the probability of port and inland mode choice is depended on some variables related to the port and inland mode characteristics. The port hinterland connectivity variables except for inland mode reliability (no data available, thus it is assumed to be 80% for all alternatives) have a specific value for each zone area. The port performance variables applied are refer to Munajat [10] as provided in Table 2.

Table 2. Port performance

Port	Port cost (thousand Rp)	Port ship call
Tanjung Priok	1127	82
Tanjung Emas	1098	12
Tanjung Perak	1154	23
Patimban[4]	1126	82

3.1 Port Hinterland Boundaries

From the probability of port and inland mode choice value, we can also infer the information about the port hinterland boundaries. A high probability of a particular port indicates that the respective area is the hinterland area of the port. The hinterland boundaries of the Tanjung Priok Port presumed by the probability value can be seen as in Figure 1. Further, by the operation of Patimban Port, Tanjung Priok Port and Patimban port's hinterland boundaries are quite overlapping due to the proximity between these two ports that reduce the demand of Tanjung Priok (see Figure 2).

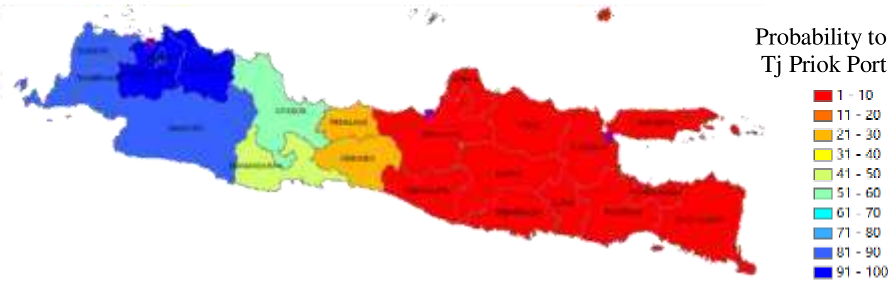
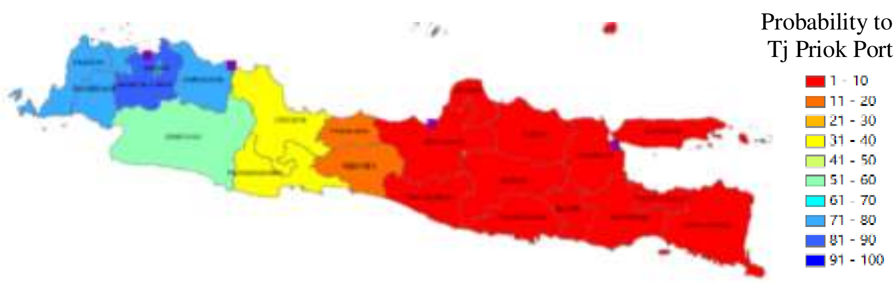


Fig. 1. Hinterland boundaries of Tanjung Priok port prior to Patimban port operation



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[4] Patimban port is not yet operated. However, as Patimban port is expected to be the biggest port in Java, hence all of the port performance values are assumed to be the same as Tanjung Priok Port which currently is the biggest port.

Fig. 2. Hinterland boundaries of Tanjung Priok port after Patimban port operated

3.2 Elasticities

The effect of changes in each variable on the probability of alternative could be expressed through the elasticity value. Elasticities can be calculated as percent changes of probability in response to one percent changes in the observed variables. Table 4 depicts the elasticities of probability choosing Tanjung Priok port as a service port and truck as the port hinterland transport mode from three zones, namely Jakarta, Cirebon, and Surabaya. Those three zones are selected to represent zones with high, medium, and low probability. Probability value close to 1 is assumed as high probability, and close to 0 is assumed as low probability, while medium probability is around 0.5.

Table 3 shows that the probability of choosing Tanjung Priok port by using truck mode for Jakarta area is inelastic demand (10% reduction of inland mode time cause only a 0.76% increase in probability). It means almost all containers from Jakarta will be choosing Tanjung Priok via road transport even if there are big changes in the observed variables. Unlike Jakarta, which has inelastic probability, the probability form Cirebon area is elastic (i.e., 10% increase in inland mode time could drop the probability of choosing Tanjung Priok port using truck by 9.30%). It means that the container demand from this area is potentially shifting to other ports if the port hinterland connectivity variables or the port performance are getting worse. For Surabaya, even though its probability elasticity is high, as the initial probability is low; hence the probability changes will not be very substantial. This result is in line with the derivative theory of MNL modelling. The impact of observed variable changes is higher when the degree of uncertainty from the probability is high (P around 0.5). Meanwhile, the impact of changes will be diminished when the probability is almost certain (P close to 1 or 0) [11].

Table 3. Elasticities of probability choosing Tanjung Priok port using Truck as inland mode respect to the one percent increase of observed variables in Jakarta, Cirebon, and Surabaya

	Jakarta	Cirebon	Surabaya
The probability to Tanjung Priok port using Truck	93.67%	43.78%	0.33%
Inland mode cost	-0.003	-0.055	-0.195
Inland mode time	-0.076	-0.930	-2.772
Inland mode GHG emission	-0.005	-0.693	-4.058
Inland mode reliability	0.098	0.868	1.539
Port cost	-0.029	-0.251	-0.467
Port ship call	0.035	0.046	0.157

3.3 Transport Policies and Estimation Result

In this section, the multinomial logit (MNL) model will be used to estimate the probability of port and inland mode demand in Java. For this simulation, three zones with probability of around 50%, namely Cirebon, Kebumen, and Trenggalek will be examined. Further, the effect of two transport policiy scenarios and the operation of Patimban port on the port and inland mode demand will also be discussed. Scenario 0 represents the existing condition without transport policy implementation. The transport policy scenarios that will be simulated are:

- Scenario 1: improving the transshipment process of rail transport is expected to reduce train transport time by 20%.
- Scenario 2: investment in Tanjung Perak port is expected to double the port ship call.
- Scenario 3: Patimban port starts to operate.

The effect of these transport policy scenarios on port and inland mode demand is presented in Table 4. Improvement of rail transport as applied in scenario 1 is expected to encourage mode shifting from road to rail transport. Based on the simulation, reducing rail transport time by 20% has a high impact on boosting the demand for rail inland mode in all zones. However, the probability of using a train as the inland mode is still lower than road transport, indicating the low initial market share of rail transport. Comparing the base mode cost of road and rail transport; train is cheaper than truck. However, unlike trucks that offer cost efficiency as its cost only consider the cost from origin to destination (port), the cost component in rail transport requires an additional cost of loading and unloading process and the short-distance trucking cost that could scale up the total cost considerably. Moreover, inadequate law enforcement of overloading trucks also impacted the low market share of rail transport.

Table 4. MNL simulation result: variation of probability demand as respond to transport policy scenario in Cirebon, Kebumen, and Trenggalek

Port	Inland mode	Probability (%)											
		Cirebon				Kebumen				Trenggalek			
		Scenario				Scenario				Scenario			
		0	1	2	3	0	1	2	3	0	1	2	3
Tj Priok	Truck	43.8	38.9	43.5	31.7	15.6	13.8	15.3	13.4	1.4	1.3	1.3	1.4
	Train	11.2	15.5	11.1	8.1	7.5	11.4	7.3	6.4	0.9	1.7	0.8	0.9
Tj Emas	Truck	33.5	29.8	33.2	24.2	59.0	52.1	57.7	50.4	32.8	29.9	29.7	32.3
	Train	7.4	10.4	7.4	5.4	5.0	7.6	4.9	4.3	2.5	4.0	2.2	2.4
Tj Perak	Truck	1.8	1.6	2.1	1.3	6.9	6.1	7.9	5.9	50.4	45.9	53.3	49.5
	Train	2.3	3.7	2.7	1.7	6.0	9.1	6.8	5.1	11.9	17.2	12.6	11.7
Patimban	Truck	0.0	0.0	0.0	22.9	0.0	0.0	0.0	9.7	0.0	0.0	0.0	1.0
	Train	0.0	0.0	0.0	4.7	0.0	0.0	0.0	4.9	0.0	0.0	0.0	0.7

The second scenario is expanding the port performance, for example, by planning investment on Tanjung Perak port. By developing the Tanjung Perak port's infrastructure, it is expected that enlarging the pier will pull the number ship calls from 23 to 46. Referring to Table 5, the effect of increasing port performance positively impacts the port choice. The probability to Tanjung Perak port increases in all zones for both road and rail inland modes. It is quite explicit that by providing better performance on Tanjung Perak port, the shipper will be more attracted to shipping their containers through this port.

The last scenario is the operation of Patimban port which is expected to be fully operated in 2027. Cirebon has the highest port demand shifting from Tanjung Priok port to Patimban port, followed by Kebumen. In contrast, Trenggalek has slight port shifting from Tanjung Perak port to Patimban (about 1%). The high impact of Patimban port on Cirebon, which is located in West Java area is apparently due to close proximity to this port, and the assumption that both ports, Patimban and Tanjung Priok, are similar in port performance make the hinterland boundaries hazier (see Fig. 1 and Fig. 2).

4 Conclusion

This paper has demonstrated the use of a multinomial logit model to identify the port hinterland boundaries and the impact of changes in observed factors on the probability demand of port and inland mode. The transport time and reliability of inland mode are variables from the port hinterland connectivity category that greatly affects the joint demand of port and inland mode. At the same time, the number of port ship calls has the highest impact from the port performance category. From the simulation on several transport strategies, introducing Patimban port as a new container port in Java will significantly impact Tanjung Priok port's demand. Reducing rail transport time and improving port performance also impacted in encouraging port and mode shifting for container transport in Java.

5 Acknowledgements

The authors wish to thank the Directorate of Higher Education, Ministry of Education and Culture, the Republic of Indonesia for financial support for this research. The authors also wish to thank the Universitas Sebelas Maret Surakarta for the support on this publication. The authors are also grateful to anonymous reviewers for their suggested improvements to this paper.

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