MULTIMODAL FREIGHT TRANSPORT NETWORK PLANNING

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Abstract: To handle the potential freight transport market within the archipelago like Indonesia will require a variety of transport modes. Seaport development should in the future be connected with its hinterland through an efficient road and rail links. As regional road and rail network is still under development in the region, when a port is being planned it is crucial to investigate its integration with the existing or planned land transport network. The advantage of one mode over the other should be taken into consideration when planning the national transport system.

The objective of this paper is to report the progress of on going research on multi-modal freight transport network modeling. STAN, a regional strategic analysis and planning of freight transportation software, is verified and used to produce an overall estimation of the movements of freight of all products, by all of the modes available.

Keywords: multimodal, multiproduct, freight, network, model

1. INTRODUCTION

1.1 Background

Transportation services for a vast archipelago country like Indonesia demand various modes of transport, including land, sea and air transport. However, the operational network efficiency of the existing national transport market, particularly for freight, can not be measured as no indicator is available in multi-modal network-wide basis. Although, it is generally accepted that given the trip demand, the trip length and cost of travel, each mode will have relative operational merits compared to the others.

The shortcomings of the concept of national transportation system that Indonesia has so far are a poor exercise on the pattern of multi-modal transportation network. Policy tools have not been provided to allow us to study this particular issue. National survey on freight and passenger demand has been performed, at least twice in the last decade. The results, however, can only be utilized as basic information for national or regional distribution of freight transportation demand. Such information, in fact, is not static, it changes depend on the situation of transportation market, the land use setting, and the policy framework at the time the survey was conducted.

Recently a study on freight transport demand modeling for Indonesia application was conducted (Sjafruddin et al., 1999) with the case on the Java Island. It developed various freight demand models for a number of transport modes. The models were calibrated against data from the 1996 National O-D (Origin–Destination) Survey. The modeling approach employed was the so-called simultaneous demand model (or sometimes also called the direct demand model). The model estimates the number of travel demand between a pair of origin-destination utilizing a particular mode of transport in a certain route. However, the model does not explicitly model route or freight assignment; rather it assumes that there is only one route available for every mode between every pair of origin-destination. Although, its demand modeling in some respects may constitute implicit network modeling, it is urgent in the future to develop a real network based modeling while utilizing the freight demand model as an exogenous inputs.

1.2 Objectives

Based on the conventional trip-based transport model, the proposed research will explicitly consider freight network into the model structure, with specific objectives (i) to verify the user of STAN and (ii) modeling freight transportation in a hypothetical network and a real network of Java.

This research is specifically directed to study an efficient pattern of multi-modes and multi-products national freight transportation network in support of the foregoing effort in the formulation of the national transportation system. Data obtained from national freight origin-destination surveys will be enhanced to become the exogenous input into the model. This will enable us to test various policies related to spatial development and freight transport regulations adapted now or in the future.

2. FREIGHT TRANSPORT NETWORK MODEL

In modeling freight transportation systems, models have been developed by researchers from many disciplines using many different approaches in an attempt to solve many different problems. This is just one indication that freight transportation involves a complicated decision-making process (Chiang, et. al., 1980).

The developed models can be classified into two groups, according to model specification, i.e. models with decision-making process and models without decision-making process. Models without decision-making process just include analysis, which concentrate on predicting demand or performance of supply only. The behavior component in the decision-making system is never modeled, so its use in investment problems and source allocation is limited.

There are many models with decision-making process that have been developed and recommended, but until now, no standard have been agreed upon. This is due to a complicated interaction between components in a freight transportation context.

2.1 Conceptual Model of Freight Transportation System

The general purpose of a freight transportation system is to allow for the availability of goods for production and consumption at various locations, given the availability of natural resources, and needs of suppliers and consumers of goods. Its main function is among others, to: facilitate the economy. Within the freight transportation system, a large number of processes can be observed which together enable this necessary function to be fulfilled. These processes themselves consist of many activities that can be observed in the freight transportation system like blending, sorting, storage, packaging and stuffing.

Selected problems can be described by a set of options that decision-makers select from a set of policy rules. In the above scheme, selected problems are characterized by the options available to the decision-maker. The main selections that appear in the literature relate to the following types of options (see Harker, 1987; Kanafani, 1983; Ortuzar and Willumsen, 1990):

1. production and consumption locations
2. the nature and volume of goods to be consumed
3. the nature and capacity of production processes
4. the location of warehouses
5. product pricing
6. buyers and suppliers
7. the choice of mode(s)
8. the size and frequency of shipments
9. the size of inventories
10. vehicle assignment and scheduling
11. routing between origins and destinations

In order to keep the complexity of the conceptual model within manageable limits, the selections can be grouped into three levels of analysis, according to the time frame to which they apply:

1. The locational level describes the land use characteristics, for example: the locations where goods are produced, stored or consumed.
2. The relational level involves the process of spatial distribution of goods between locations of demand and supply.
3. The transport operations level comprises the use of services and facilities for the physical act of transportation.

The basic decision-making is usually done by an individual or by a group of persons within an organization, such as a management team. On some occasions, producers control the way in which processes at all three levels take place; however, many other configurations of decision makers are possible in the system (Winston, 1981). The decision-makers within a freight transportation system are denoted as *agents*, and identified by means of option that they select. In the conceptual model, the following agents contribute to the flow of goods in a system (Harker, 1987; Tavasszy, 1996):

- Producers decide on the location and the nature of the production process and the price of the product.
- Consumers decide on the nature and volume of goods to be purchased from producers, and where to buy these goods.
- Shippers decide on the distribution and frequency of goods movements, on the characteristics of the shipments, and on the mode(s) of transport.
- Carriers are the agents who perform the transportation activity itself, and in principle operate with one mode of transport.
- Government provides the legislative and infrastructural framework for the processes in the system.

A summary of conceptual models that pertain to the decision maker in a system, and their selection problems can be seen in Table 1.

Table 1. Selection Problems in the Three Levels of Analysis

No.	Selection Problem	Level	Process	Agent
1.	Locations of production and consumption	Location	Generation (production, consumption)	Producer, consumer
2.	Nature and volume of goods to consume			
3.	Nature and capacity of production processes			
4.	Location of warehouses			
5.	Price of the products			
6.	Buyer/supplier relationships	Relations	(multimodal) distribution	Shipper
7.	Size and frequency of shipments			
8.	Size of inventories			
9.	Choice of mode(s)			
10.	Vehicle/load unit assignment and scheduling	Operations	(multimodal) transport	Carrier
11.	Routes between origins and destinations			

Source: Tavasszy, L. A. (1996)

2.2 STAN Package Software

STAN stands for Strategic Transportation ANalysis. STAN was developed by Crainic, Florian and Larin from the University of Montreal, Canada. It is an interactive graphic multimode multiproduct system for national or regional strategic planning of freight transportation. The strategic level of planning implies a medium to long term time horizon and a rather aggregate level of detail for the representation of the transportation infrastructure and provided services.

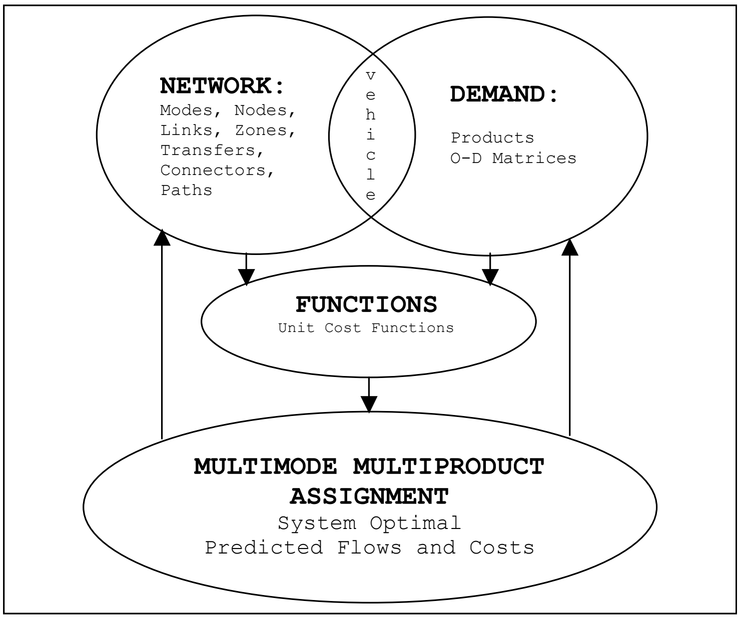


Figure 1. STAN Model Components

The primary role of STAN is the comparison and evaluation of alternatives. The contemplated alternatives normally represent major changes to the transportation infrastructure or important modifications to the operating policies and cost structures.

The simulation of freight flows is carried out on these scenarios as well. Subsequently, flows, link costs, delay and congestion, intermodal shipments, infrastructure utilization and other performance factors may be compared between different scenarios.

The network optimization model that is used to simulate network flows in STAN is a nonlinear multimode-multiproduct assignment formulation that minimizes the total generalized system cost.

The generalized cost is computed for each link and transfer of the network, as a weighted sum of an operating cost function, a delay function and an energy consumption function.

This modeling framework provides both an adequate representation of large multimode-multiproduct transportation systems for strategic planning purposes and a mathematical structure well suited for efficient solution methods; even large problems are solved on small computers. Figure 1 displays the main elements of the STAN modeling framework.

2.2.1 The STAN Data Bank

The STAN data bank contains all the information that is necessary in order to engage in the strategic planning of freight transportation. It contains representations of the transportation system and the specification of the transportation demand in the area studied, as well as models of the socioeconomic criteria that explain the distribution of this demand over the network. In STAN, this information is represented as networks, matrices and functions. Figure 2 contains schematic representation of the STAN data bank.

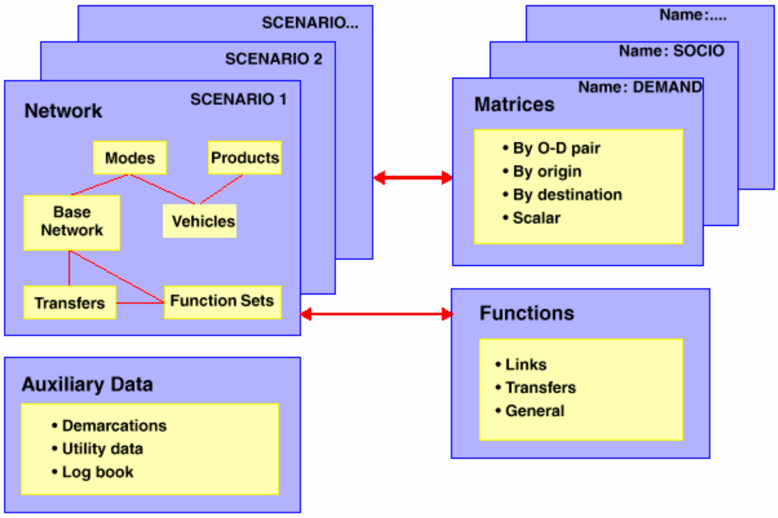


Figure 2. Schematic Representation of STAN Data Bank

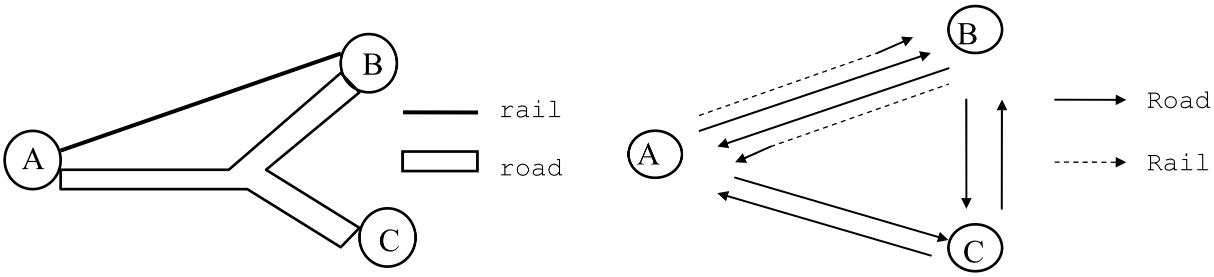
The STAN data bank is structured to permit the simultaneous descriptions and analysis of several network alternatives (or scenarios). Redundant data is not stored but is generated as required. STAN modules are independent and communicate exclusively with the data bank; no inter-module communications may take place. This approach, combined with a strictly enforced data hierarchy and a no-delay philosophy regarding data access and modification, ensure that the data bank is always in coherent state.

2.2.2 The Network Editor

The modules of the Network Editor offer the user tools to build, display and modify, interactively when appropriate, a representation of the transportation infrastructure or services, available or contemplated, in the study area. The modeling framework that STAN offers for the representation is that of a multimodal network, made up of modes, nodes, links and transfers, on which multiple products are to be moved by specific vehicles and convoys between given origin and destination points.

The network infrastructure, represented by the network model chosen, supports the transportation of several products on several modes. A product is any commodity (collection of similar goods or passengers) for which a traffic demand is defined, and that generates specific network flows. Defining the typical vehicles that carries its product on each mode specifies how products are moved on the network.

Guelat et al. (1990) proposed modeling intermodal transfers to accommodate intermodal change at a node transfer. The basic idea of this model is modification of network representation, which considers the intermodal change movements. In this context, parallel representation and exploring node was chosen as network representation technique. Figure 3 (b) depicts a parallel representation for simplified representation of a real network. Figure 4 depicts the explosion node for a node transfer.



(a) Real Network (b) Parallel Representation

Figure 3. Simplified Network Representation

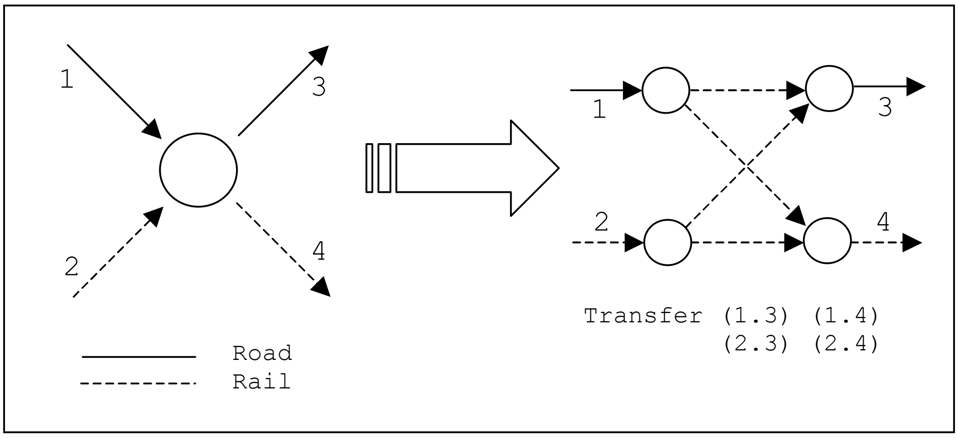


Figure 4. Explosion of a Node to Accommodate a Mode Transfer

Such a node explosion can also be adapted for commodities transfer to and from seaport to other mode of transport. Function (see section 2.2.4) is associated with network links and transfers, for all products defined in the data bank, in a most efficient and compact way via function sets. Several links (transfers) may share the same function set. Once an assignment has been performed, product flows, unit and marginal costs are associated with links and transfers as well.

2.2.3 The Matrix Editor

The matrices that are handled in STAN may be full matrices, origin or destination vectors and scalars. They contain various data related to the area studied: observed or predicted origin-demand data for various products, figures of production by origin and of consumption by destination, socio-economic statistic such as operation, industrial density, etc.

Matrices may be both an input to and an output from a computational procedure, and may be entered, modified and graphically displayed by using the Matrix Editor, which is the same as that of EMME/2. The graphical display of the contents of a matrix is performed by means of bars of width proportional to the value associated with an origin-destination pair or with a node, considered as an origin or a destination. All interactive-graphic commands are available for this purpose. Histograms, based on the contents of matrices, may also computed, compared and graphically displayed.

For strategic planning purposes, the demand for transportation cannot be individually considered for each possible node of the network. This would generate unmanageably large O-D matrices and would explode both model size and the computational time required by the algorithms, without improving the forecasts made. Zones, which contain several nodes in a contiguous geographical area, are defined and the transportation demand is aggregated accordingly. Each zone is then represented in the network by a centroid.

2.2.4 The Function Editor

STAN allows the use of a wide variety of functions, which may be specified for links as well as for transfers, to represent the various factors, such as cost, time, reliability, energy, possible environmental or hazardous impacts, etc., that determine how the transportation system is used to move the demand. Up to three functions may be specified on a link (transfer) for each product defined in the current scenario. Link and transfer functions are unit cost functions; they are multiplied by the product volumes, and then combined according to user specifications, to form the generalized cost objective function used to assign the commodities to the multimodal network.

Any function may be associated to any scenario defined in the data bank. When required, a function is evaluated with data that corresponds to the variables specified by the user in the algebraic expression that defines it. In addition to these, the user is free to define and display functions that are not linked to the information in the data bank, and that are not employed in any one of the standard calculations of STAN.

3. OUR PROGRESS TO DATE (IMPLEMENTATION ON JAVA ISLAND FREIGHT TRANSPORT NETWORK)

3.1 Data Representation

A. Zoning System

The study area is divided into several smaller areas called zones. The zoning system considers the availability of database for easier modeling. It was decided to use the administrative boundary as a zoning base. There are 78 Kabupatens and 26 Kotamadyas in Java Island. By grouping a Kotamadya to the nearest Kabupaten as one zone, and according to their development area (Wilayah Pengembangan/WP), the number of zones become 20, as displayed in Table 2 shows the grouping of zones.

Table 2. Zone Groups for Zoning System in Java Island

Zone Group Code	Kab/Kodya (Zone)	Kab/Kodya Area (Zone Group)
1.	Jakarta & DKI Buffer	Jakarta, Jakarta Selatan, Jakarta Timur, Jakarta Pusat, Jakarta Barat, Jakarta Utara, Unknown Jakarta, Purwakarta, Karawang, Bekasi, Tangerang
2.	Merak	Serang, Pandegelang, Lebak, Rangkasbitung
3.	Cirebon	Kuningan, Kab/Kod Cirebon, Majalengka, Indramayu

Table 2. Zone Groups for Zoning System in Java Island (*continuation*)

Zone Group Code	Kab/Kodya (Zone)	Kab/Kodya Area (Zone Group)
4.	Bopunjur	Kab/Kod Bogor, Cianjur, Kab/Kod Sukabumi
5.	Cekungan Bandung	Kab/Kod Bandung, Subang, Sumedang
6.	Ciamis	Garut, Tasikmalaya, Ciamis
7.	Subosuko	Boyolali, Klaten, Sukoharjo, Wonogiri, Karanganyar, Sragen, Kod Surakarta
8.	Semarang-Demak (Kedungsepur)	Demak, Kab/Kod Semarang, Kendal, Kod Salatiga, Grobogan
9.	Bregas	Batang, Kab/Kod Tegal, Brebes, Kab/Kod Pekalongan, Pemalang
10.	Karesidenan Pati	Blora, Rembang, Pati, Kudus, Jepara
11.	Purwokerto	Banyumas, Purbalingga, Banjarnegara, Cilacap
12.	Kedu	Kebumen, Kab/Kod Magelang, Purworejo, Temanggung, Wonosobo
13.	D.I. Yogyakarta	Bantul, Sleman, Yogyakarta, Kulon Progo, Gunung Kidul
14.	Gerbangkertosusila	Sidoarjo,, Kab/Kod Mojokerto, Jombang, Lamongan, Gresik, Bangkalan, Sampang, Pamekasan, Sumenep, Kod Surabaya
15.	Probolinggo-Pasuruan	Kab/Kod Probolinggo, Pasuruan, Lumajang, Kab/Kod Pasuruan, Kab/Kod Malang
16.	Bojonegoro	Bojonegoro, Tuban
17.	Kediri-Tulung Agung-Blitar	Trenggalek, Tulungagung, Kab/Kod Blitar, Kab/Kod Kediri
18.	Situbondo-Bondowoso-Jember	Jember, Bondowoso, Situbondo
19.	Madiun	Pacitan, Ponorogo, Nganjuk, Kab/Kod Madiun, Magetan, Ngawi
20.	Banyuwangi	Banyuwangi

B. Network Data

Figure 5 depicts a land transport network in Java Island, Indonesia. In this study only land transport (road and rail) were considered, with 16 nodes available for modal transfers, as a limitation to the implementation and analysis stage. Node transfers are locations where intermodal transfers of freight take place. Table 3 shows the 16 nodes that are included as transfer nodes.

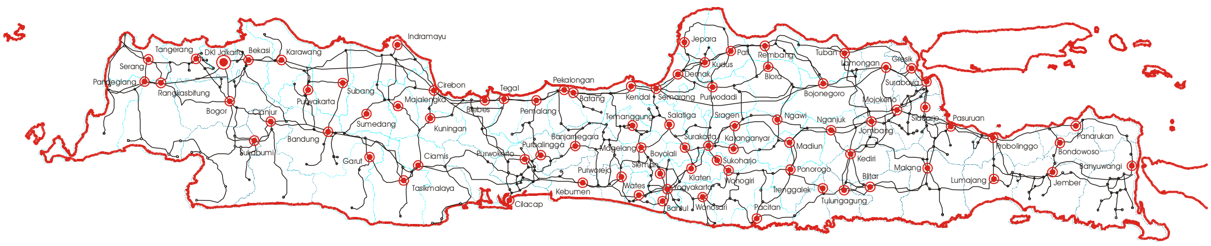


Figure 5. Road Network in Java Island, Indonesia

Table 3. Transfer Nodes in Java Island

No.	Node Code	Transfer Node Location	No.	Node Code	Transfer Node Location
1.	501	Merak	9.	578	Semarang
2.	509	DKI Jakarta	10.	589	Surakarta
3.	519	Bandung	11.	611	Bojonegoro
4.	534	Cirebon	12.	616	Surabaya
5.	541	Tegal	13.	626	Banyuwangi
6.	546	Purwokerto	14.	633	Malang
7.	548	Kroya-Banyumas	15.	639	Kertosono
8.	570	DI Yogyakarta	16.	647	Madiun

In the base condition road was categorized depending on its function for carrying freight transport. First category is primary route, i.e. PANTURA (Pantai Utara) or the Java north coast corridor. Second category is secondary route, i.e. ‘JALUR SELATAN’ or south corridor and ‘JALUR TENGAH’ or middle corridor. And third category is the alternative routes.

C. Cost Function

Total Travel Cost Function for Java network follows the equation:

$$C = \alpha * T + RPK * D$$

where : C = Total Travel Cost in Rp.

α = time value in Rp./60 second; α_{road}=4,74; α_{rail}=1,25; and $\alpha_{transfer}$ = 9,48

T = moving time in Second

D = distance in Km

RPK = specific parameter “Rp./ Km”; 0,131 for road; and 0,087 for rail.

Characteristic mode according to function link cost following equation:

$$T = t_o + aV^n$$

where : T = moving time in second

t_o = moving time in *free-flow* in second; $t_{o\ road}$ = 10; $t_{o\ rail}$ =25, and $t_{o\ transfer}$ = 50

V = link volume in ton

a = constant; a_{road} = 0,05, a_{rail} = 0,09, dan $a_{transfer}$ = 2,00

n = constant; n_{road} = 1,70, n_{rail} = 1,50, dan $n_{transfer}$ = 1,00

3.2 Modeling Results For Single Product

A. Base Case - Do Nothing Condition

Figure 6 and Figure 7 show flow pattern for Java network in do nothing scenario for road and rail mode.

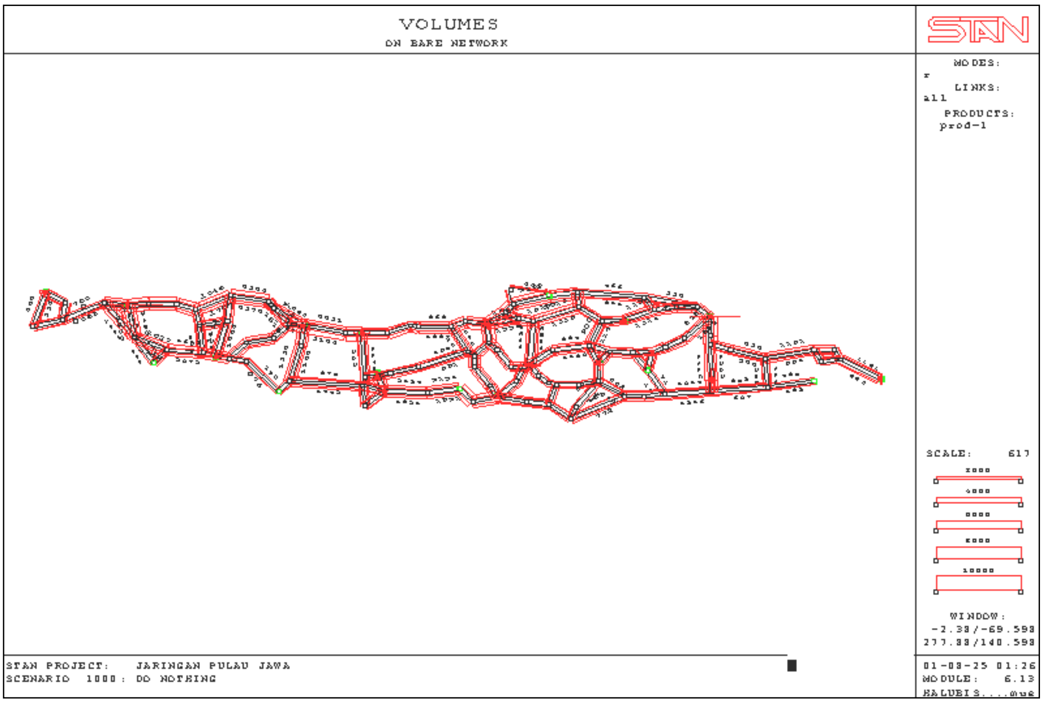


Figure 6. Flow Pattern Road Mode in *Do Nothing* Scenario

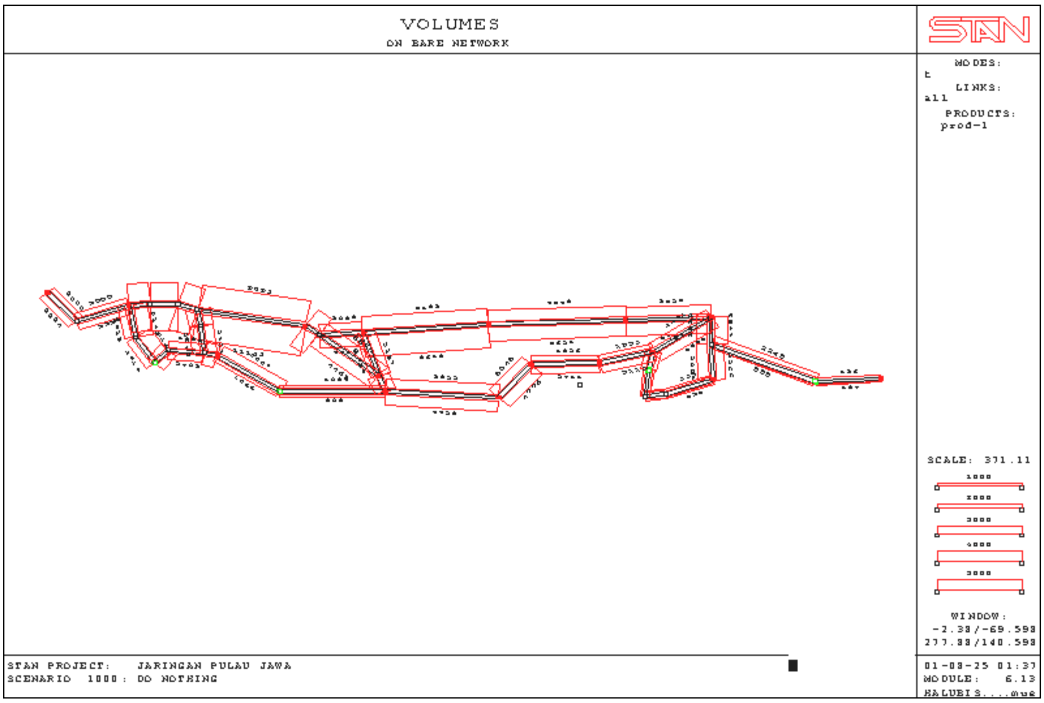


Figure 7. Flow Pattern Rail Mode in *Do Nothing* Scenario

An intermodal transfer, modeled as a node transfer, is displayed in Figure 8. In this figure, the DKI Jakarta node is blow up as an example. It can be seen that intermodal transfer is available and modeled as well.

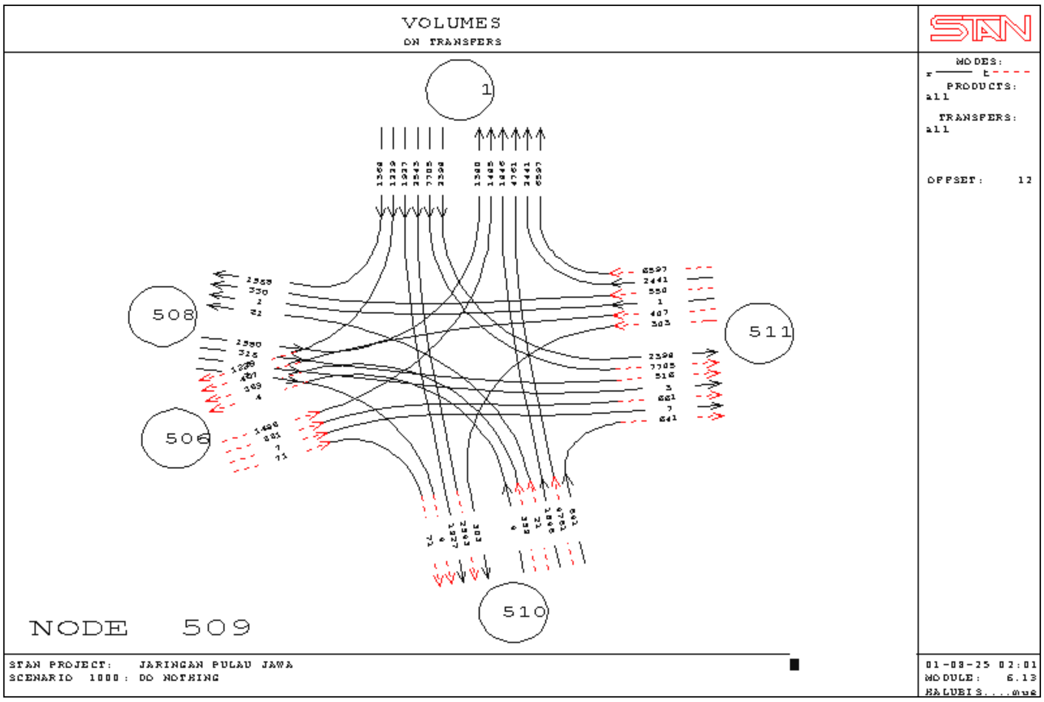


Figure 8. Intermodal Transfers at DKI Jakarta

B. Do Something Condition

In the do something condition infrastructure investment was applied on road or rail modes, and potential savings were compared between road and rail modes.

B.1 Road Investment – Do Something A

Road investment was represented through improvements on some road links in the study area, as can be seen in Table 5.

Table 5. Road Improvement – Do Something A

No.	Link Description	Category Improvement
1.	Cileunyi-Nagrek-Tasikmalaya-Ciamis-Wangon	2 to 1
2.	Yogyakarta-Klaten-Surakarta-Sragen-Ngawi	2 to 1
3.	Ngawi-Nganjuk-Jombang-Mojokerto-Surabaya	2 to 1
4.	Semarang-Godong-Purwodadi-Blora-Bojonegoro-Babat	3 to 2
5.	Yogyakarta-Wonosari-Pacitan-Trenggalek-Tulungagung-Blitar	3 to 2

B.2 Rail Investment – Do Something B

The rail investment scenario was represented with double track rail developments, as can be seen in Table 6.

Table 6. Double Track Rail Developments – Do Something B

No.	Rail Links	Status
1.	DKI Jakarta-Bogor	Existing
2.	DKI Jakarta-Bekasi-Karawang-Cikampek	Existing
3.	Cikampek-Purwakarta-Padalarang-Bandung	-
4.	Cikampek-Cirebon	-
5.	Bandung-Tasikmalaya	-
6.	Tegal-Pekalongan-Semarang	-
7.	Yogyakarta-Klaten Surakarta	-
8.	Kertosono-Jombang-Mojokerto-Surabaya	-

The equilibrium solution for Do Something A (road investment) is summarized in Table 7, and for rail investment in Table 8. Table 7 and 8 also show the differences that may be available if the investment is implemented.

Table 7. Optimum Solutions for the Java Network – Road Investment - Do Something A

	Java Network – Road Investment				
	Total Travel Cost	Road Usage		Rail Usage	
Do Nothing	Rp 447,056,184	Rp 254,461,040	56.92%	Rp 192,595,144	43.08%
Do Something A	Rp 443,385,160	Rp 252,480,608	56.94%	Rp 190,904,552	43.06%
Difference	**0.82%**				

From Table 7 can be seen that, when comparing optimum results of do nothing and do something A, the road investment scenario achieves a better solution. The do something A results in a 0.02% rail mode usage, in terms of Rp., diverting to road. This yields a different of 0.82% of the total transport cost relative to the base condition.

Figure 9 and Figure 10 show flow pattern for Java network in do something A scenario for road and rail mode.

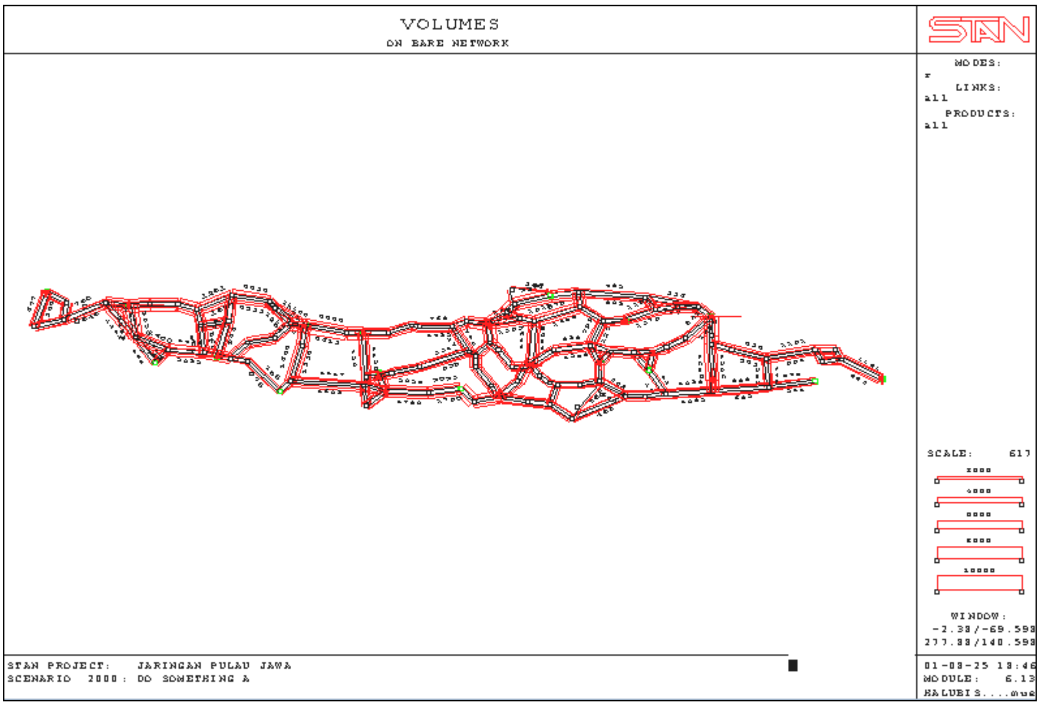


Figure 9. Flow Pattern Road Mode in *Do Something A* Scenario

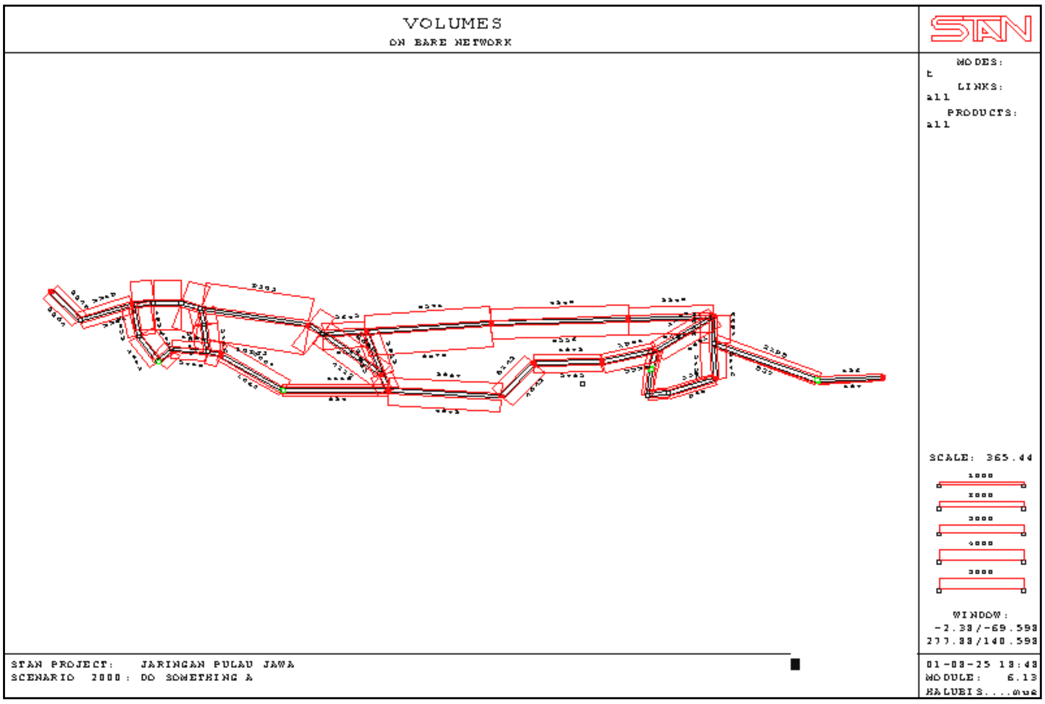


Figure 10. Flow Pattern Rail Mode in *Do Something A* Scenario

Table 8. Optimum Solutions for the Java Network – Rail Investment - Do Something B

	Java Network – Road Investment				
	Total Travel Cost	**Road Usage**		**Rail Usage**	
Do Nothing	Rp 447,056,184	Rp 254,461,040	56.92%	Rp 192,595,144	43.08%
Do Something B	Rp 369,605,660	Rp 195,079,952	52.78%	Rp 174,525,708	47.22%
Difference	**17.32%**				

From Table 8 can be seen that, when comparing optimum results of do nothing and do something B, the road investment scenario achieves a better solution. The do something B results in a 4.14% rail mode usage, in terms of Rp., diverting to road. This yields a different of 17.32% of the total transport cost relative to the base condition.

Figure 11 and Figure 12 show flow pattern for Java network in do something B scenario for road and rail mode.

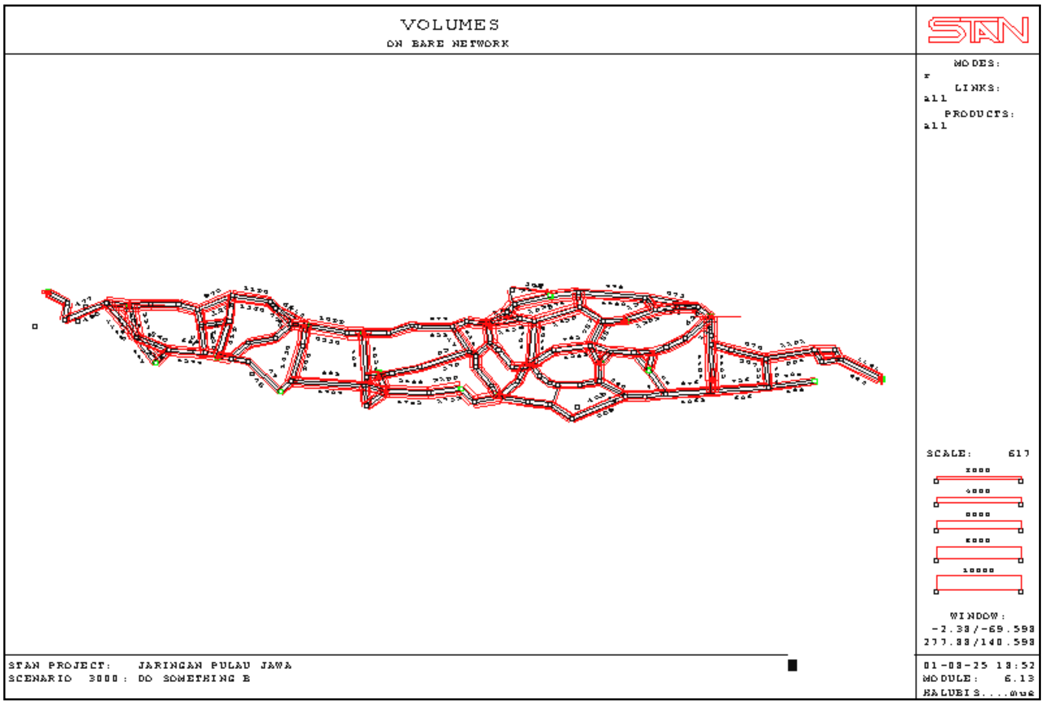


Figure 11. Flow Pattern Road Mode in *Do Something B* Scenario

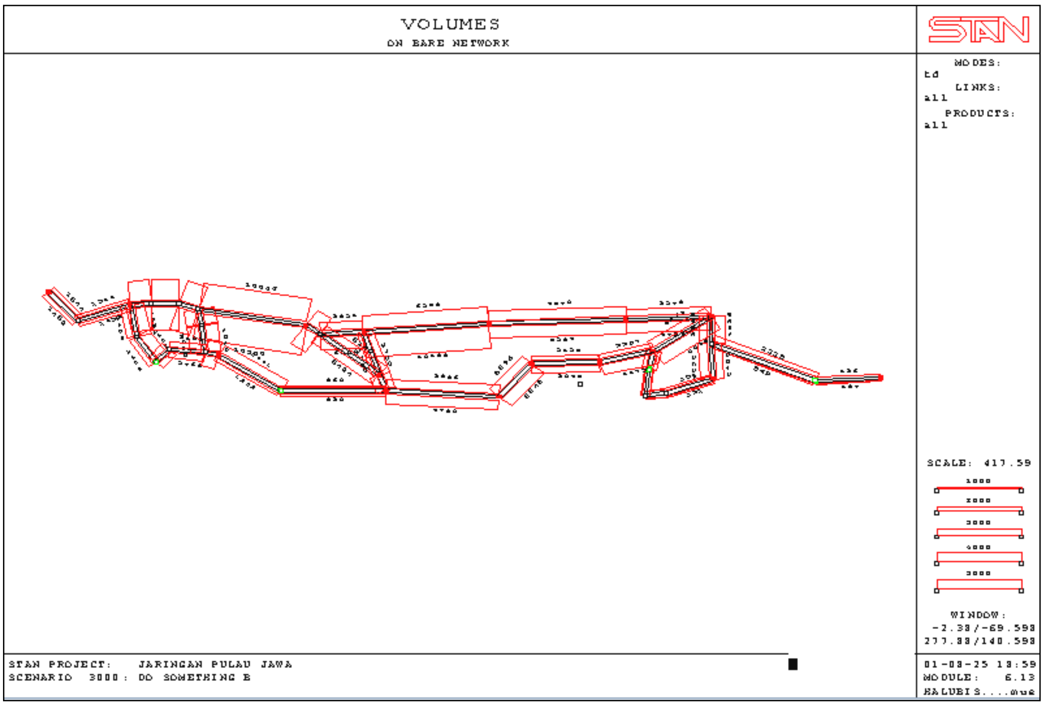


Figure 12. Flow Pattern Rail Mode in *Do Something B* Scenario

C. Network Scenario in 10 Years

Future assumption will be made where demand in 10 years will be twice as much compare to demand in 1996. Table 9 and Figure 13 will compare the Total Travel Cost in both scenarios which is *do something A and do something B.*

Table 9. Total Travel Cost for each scenario in 10 years

	Total Travel Cost		
	Do Nothing	**Do Something A**	**Do Something B**
On Link	Rp 707,653,312	Rp 721,366,272	Rp 530,054,208
On Transfers	Rp 895,378,432	Rp 878,718,464	Rp 747,747,904
Total	Rp 1,603,031,744	Rp 1,600,084,736	Rp 1,277,802,112
Different with do nothing		**0.18%**	**20.29%**

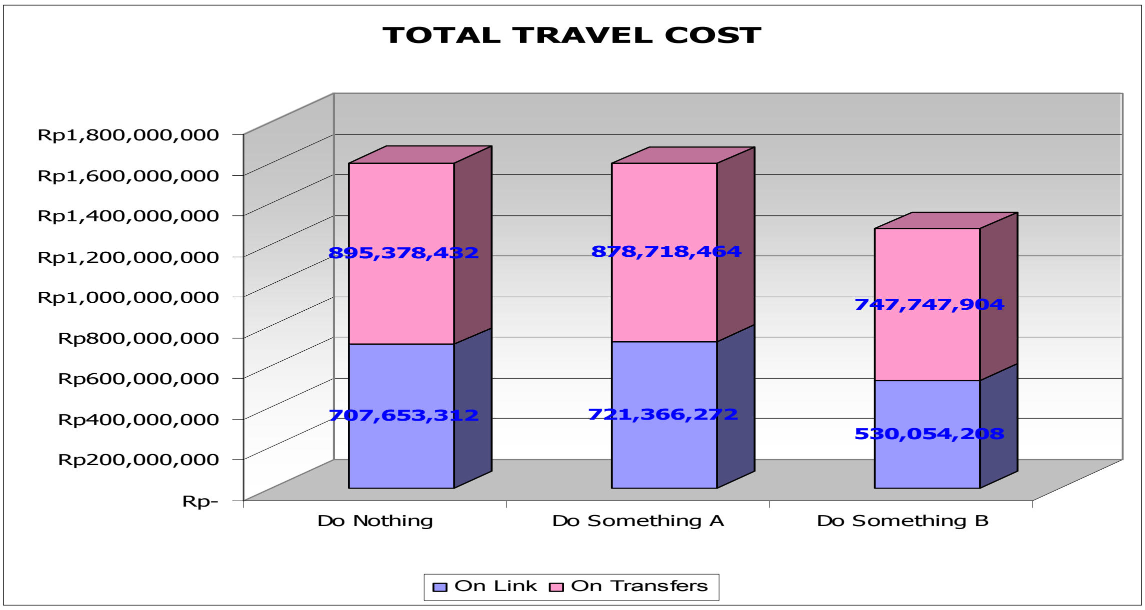


Figure 13. Total Travel Cost Histogram for each scenario in 10 years

Conclusion can be made by comparing Total Travel Cost from Table 7, Table 8 and Table 9, that do something A scenario (road investment) gives smaller difference in 10 years that is 0.18% comparing to present condition which is 0.82%. Do something B scenario gives bigger difference in 10 years that is 20.29% comparing to present condition which is 17.32%.

3.2.3 Modeling Results for Multi Product

Table 10. Total Travel Cost for Multi Product Case in Java Island Network

	Total Travel Cost - Multi Product - Do Nothing (in Rupiah)						
Road – Rail	**100% - 0%**	**90% - 10%**	**75% - 25%**	**50% - 50%**	**25% - 75%**	**10% - 90%**	**0% - 100%**
On Link	199,731,888	169,503,354	123,056,816	63,081,678	23,979,466	8,087,149	606,653
On Transfers	247,324,288	207,724,927	152,930,318	83,048,412	31,691,186	9,596,550	591,181
Total	447,056,176	377,228,281	275,987,134	146,130,090	55,670,652	17,683,699	1,197,834
Saving		**15.62%**	**38.27%**	**67.31%**	**87.55%**	**96.04%**	**99.73%**

Multi product demand will be implemented with assumption there are proportion share of rail and road demand, based only on base network (do-nothing). While the case for alternative network expansion will be subject for further investigation. In this case it can be concluded that total travel cost increase when road demand has bigger proportion than rail demand. Table 10 and Figure 14 depict total travel cost for multi product case.

Table 10 shows, if all demand share to rail (0%-100%), total travel cost gives 99.73% saving compared with single product case.

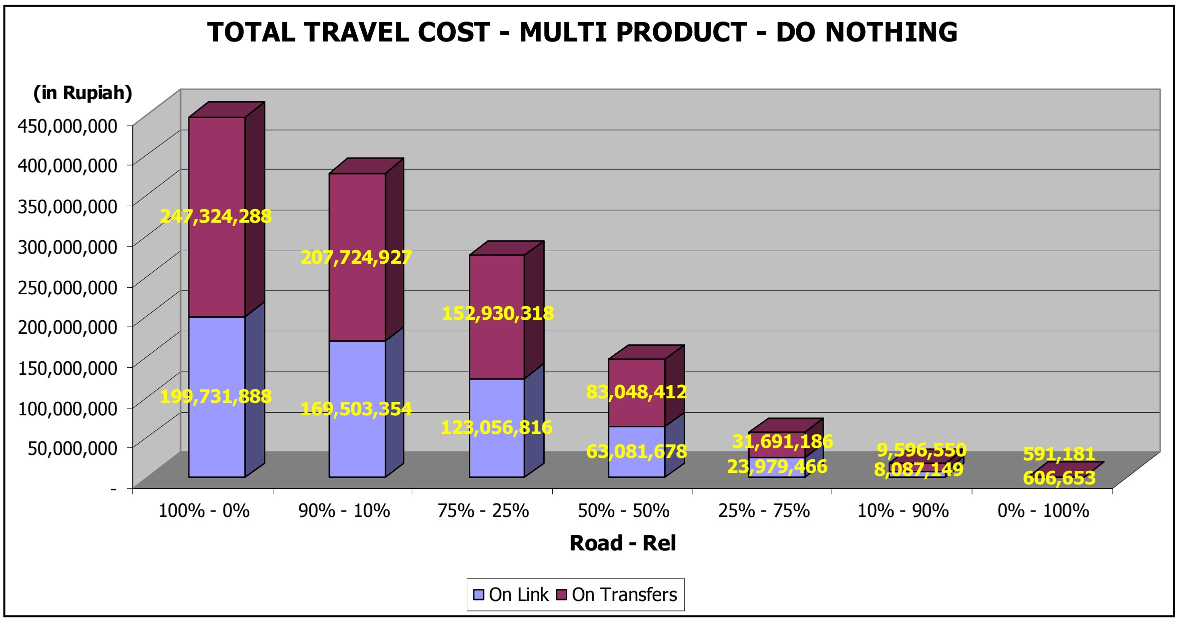


Figure 14. Total Travel Cost Histogram for Multi Product

4. CONCLUSION AND RECOMMENDATION

In a single commodity case, in terms of total travel costs, it was found that rail expansion is more beneficial than of road expansion. Network improvement through rail expansion gives benefit of 17% compared to the do-nothing case, while road only 1% in the base year. Examination with two commodities also shows that rail expansion performs better than that of road.

By using STAN In the future further activities are required in order to improve the current achievement, particularly in the area identified below:

a. To extend the scope of study so that more modes can be accommodated through defining the characteristics of modes by using a modification of the cost function, and more commodities can be accommodated, depending on the demand data available.
b. To formulate modal-commodity dependence so as to have more realistic and restricted commodity-mode assignments.
c. To implement the concept on real network cases, e.g. Indonesia network and ASEAN network.

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