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Design of Intermodal Freight Transport System for Port of Tanjung Emas:

Assessing Land Connectivity by Railway Compared to Connectivity by Road

by

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I dedicate this thesis to my parents, Uus Tamyana and Rahmi Mulia, who always support and encourage me to do better as a *person* and *human being*.

This thesis humbled me on so many occasions. The fact that difficulty shapes me better only comes when I dictate myself to be stronger.

"What is true of all the evils in the world is true of plague as well. It helps men to rise above themselves."

– Albert Camus, The Plague

Abstract

The urgency to create a more efficient transport network system is getting higher these days due to the competitiveness of the business itself. As the movement of freight contributes significantly to the price of goods, the freight transport business tends to choose cheaper and more efficient transport systems in order to maximize their profit. Various kinds of problem also arise from the traffic load of freight transport to the existing road. The congestion is happening because of the high number of vehicles operating on the road. However, developing a decent, dependable, and efficient network system needs a high capital. Thus, the planning phase is critical as it can properly ensure the benefit of the project. This research will use optimalization method to find the optimum solution for shifting network system from unimodal to intermodal system and illustrate the impact of implementing that network system by creating an isochrones map for demonstrating the travel time cluster in Port of Tanjung Emas hinterland.

Therefore, this research will simulate the movement of containers from gravity points within Port of Tanjung Emas hinterland and find the optimum routing for general movement of containers. By using the same dataset of network and gravity points, this research will also estimate the travel time from and to Port of Tanjung Emas. Those two crucial issues will be solved by two main models of this research, the Network Transport Model and Travel Time Model. Those two models will be applied in Port of Tanjung Emas hinterland data in order to find better solution of network transport and its impact to the port connectivity to its hinterland. The alternative haulage which will be analyzed in this research is railways or freight train.

By introducing the intermodal system, a lower total transportation cost and decrease in the moving time of freight can be achieved. The simulation also indicates the optimum routing and effective transfer points for the network system as each gravity point has separate tendency of choosing both routes and transfer points. As the result of implementing intermodal freight transport network system in Port of Tanjung Emas hinterland, the overall cost of transportation in the hinterland will decrease about 8.65% from the current condition of freight truck as the main haulage for its transport network system.

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List of Abbreviations

3PL – Third party logistics provider

EU – European Union

GDP – Gross Domestic Product

IFT – Intermodal freight transport

MILP – Mixed Integer Linear Programming

OD – Origin-Destination

PoTE – Port of Tanjung Emas

SWOT – Stength, Weakness, Opportunity, and Threat

TEU – Twenty-foot equivalent unit

UNCTAD – United Nations Conference on Trade and Development

YoY – Year over year

Chapter 1. Introduction

In this chapter, the background information of intermodal freight transport (IFT) or intermodality is given and explained in general, also followed by the general information of Tanjung Emas Port general information. Moreover, problems in the current transportation network of Port of Tanjung Emas hinterland are also stated generally in this chapter, followed by research question with its sub-questions. At the end of this chapter, the full list of contents that included in this report are elaborated.

1.1. Background

Intermodality is a topic that is becoming more significant in the fields of logistics and transportation due to its potential of creating better efficiency in the operation and to lessen the detrimental effects of transportation on the environment and society. The term “intermodality” or intermodal freight transport, as defined by (Crainic and Kim, 2007), is an activity of transporting cargo or any kind of load from its origin to its destination by using at least two transportation modes sequentially. One of the biggest benefits of intermodality is this operational method could tackle problems of hinterland haulage, which refers to freight transport between deep-sea ports and the origins or destination of cargoes in the hinterlands, such as limited capacities of transport infrastructures, traffic congestion and traffic emission issues (Li, Negenborn and De Schutter, 2015). However, the implementation of intermodal transportation systems can also present challenges, such as infrastructure constraints, technological barriers, and regulatory issues. This complicated things about potential problems and challenges are becoming serious issues on the development of one of the biggest ports in Indonesia, Port of Tanjung Emas.

Semarang, the Indonesian province of Central Java's capital, is home to the seaport of Tanjung Emas. It is a major hub for trade and business in the area and one of the busiest ports in the nation. The Port of Tanjung Emas is strategically located on the northern coast of Java Island, with relatively easy access to major transportation networks, including highways and railways. This makes it a convenient and cost-effective option for businesses that need to transport goods to and from Central Java and other parts of Indonesia. Indonesia has experienced a significant growth in container traffic over the years, reflecting the country's strong economic growth and rising demand for imported goods. According to the data from United Nations Conference on Trade and Development or UNCTAD (UNCTAD, 2022), the total container throughput of Indonesia in 2020 was 14.02 million TEUs and a YoY growth rate of 3.2% from 2015 to 2020.

Yearly container throughput of other ports in Indonesia is still in the range below one million TEUs (Napitupulu, Jinca and Riyanto, 2022), while Port of Tanjung Emas throughput was around 856 thousand TEUs in 2021 (Ministry of Transportation, 2022). Overall, the Port of Tanjung Emas is a crucial hub for international trade and commerce for its hinterland, also serving as a gateway to the region and connecting businesses in Central Java to markets around the world. The problem of this port connectivity to its hinterland is heavy traffic across the roads and highways near and inside the city of Semarang. The traffic happens due to high movement of people, goods, and services as Semarang is the capital city of Central Java Province with a high level of population density (100 Resilient Cities, 2016; Mudiyono and Sudarno, 2018).

1.2. Objective and Research Questions

The objective of this research is to create an overview of transport flow, cost-related properties of freight transport, and network analysis resulting from theoretical design of railway haulage in Port of Tanjung Emas hinterland. The existing network of Tanjung Emas hinterland is dominated by road transport, while this research is showing an alternative transportation network within the hinterland by using railways as its main haulage. The research specifically considers the existing roads and railways in order to analyze the network alternatives and therefore compares them in terms of efficiency.

The main question of this thesis is: "How do railways improve Port of Tanjung Emas connectivity to its hinterland?". There are several sub-research questions: 1) What is the role of railway in freight transport system of Central Java? 2) How is Port of Tanjung Emas port performance? 3) How is Port of Tanjung Emas` existing connectivity to its hinterland? 4) How is the comparison between existing connectivity and designed intermodality system in terms of efficiency?

1.3. Research Approach

This research will use quantitative approaches in order to answer its main and sub-research questions. The quantitative approaches are based on two main models of this research: the travel time and transport network model. This research will first identify the existing network conditions of Tanjung Emas Port with the geographic border of its hinterland. The network dataset derived from Geospatial Information Agency Indonesia and OpenStreetMap will be used as a basis of both models with its multiple functions such as network length, PoTE accessibility to its hinterland, and part of cost analysis. Furthermore, port related and other specific data such as port throughput and freight transport cost will be derived from other researches. The significance of implementing intermodal transport in PoTE hinterland will be assessed based on model results and followed with a discussion on how the results happened and further suggestions to improve the research.

This research will focus on comparing the existing condition and planned conditions of intermodal transport. The implementation of intermodal transport network system uses the previous throughput of Tanjung Emas Port for its demand in order to analyze the optimum route and select the best location for dry ports that can help sustaining the increase demand of PoTE in the future. The network transport model will be used in six different scenarios, containing the combination of alternatives mode and origin-destination nodes.

1.4. Structure of the Report

This thesis consists of eight chapters: Chapter 1 – Introduction, Chapter 2 – The Shift Towards Intermodal Freight Transport, Chapter 3 – Theoretical Review, Chapter 4 – General Review of Designated Port, Chapter 5 – Conceptual Framework and Hypothesis Development, Chapter 6 – Research Methodology and Data, Chapter 7 – Results, and Chapter 8 – Discussion and Conclusion.

Chapter 1 explains the basic motivation and objectives of doing this research along with lists out the research question along with the sub-research questions. Furthermore, this chapter also briefly explains the approach which will be used to analyze the problems.

Chapter 2 concludes the relevant literature from many sources regarding the development of intermodal freight transport across the globe. This chapter acts as a general introduction to the mentioned issue. To address the advantages and disadvantages of intermodal freight transport, the SWOT method concludes the findings of previous researches and reports regarding this topic at the end of the chapter.

Chapter 3 consists of theories behind the development of intermodal freight transport systems and travel time model. The explanation of those theories includes the approaches and equations for building those models.

Chapter 4 illustrates the basic knowledge of designated port for this research. It also contains the operational data of this port and the connectivity condition of this port to its hinterland.

Chapter 5 provides the buildup of theoretical framework for doing this research. By focusing on finding solutions for the problem which mentioned on its previous chapters, this chapter will explain specific methods in order to find better understanding of the problems with the models which have been slightly introduced on previous chapters.

Chapter 6 presents the methodology to solve the mentioned problems, along with all data and assumptions. The data that we used comes from various sources with some adjustment to fit the necessity of our models.

Chapter 7 is about the results of our model. By pointing out the result from both models, this chapter will function as basic argument for the next chapter. The result of those models will be represented on maps and tables of numbers.

Chapter 8 compares the result as described in the previous chapter. The main focus of this chapter is to compare the existing condition and planned condition of network system in Port of Tanjung Emas hinterland. At the end of the chapter, we explain about the limitation of doing this research and recommendation for future research.

Chapter 2. The Shift Towards Intermodal Freight Transport

The development of international trade has always been intimately related to improvements in transportation. In the past, the movement of commodities was frequently restricted to a few modes, each of which operated independently. However, a more integrated strategy to freight transit has arisen in response to growing global demand, environmental concerns, and infrastructure challenges. The rising trend towards intermodal freight transport is examined in this chapter, along with its contemporary phenomenon across the globe, and general analysis about benefit and weakness of Intermodal Freight Transport.

2.1. Introduction to Intermodal Freight Transport

As the sun sets over sprawling coastal ports, containers are seen moving smoothly from enormous ships to railcars headed for the interior or to trucks for shorter, local deliveries. This scene, which is played out again around the world, perfectly captures the spirit of intermodal freight transport—a logistical ballet designed to combine the advantages of many modes of transportation for effective goods movement. The flow of goods in a globalized society is evidence of the complex web of trade, demand, and supply. Historically, just a few modes—road, rail, sea, or air—were used to convey freight. However, the classic paradigms of freight transport are being re-evaluated as concerns over environmental sustainability have grown and global trade has become more complex.

A combination of modes is used to convey goods in intermodal freight transport, which easily switches between them. Intermodal freight transport signifies a paradigm shift in logistics and supply chain management, not just a fusion of several modes of transportation. It considers the benefits and drawbacks of each transport method and makes use of them in concert. For instance, while road transportation delivers door-to-door delivery, it may not be as energy- or money-efficient as rail or water transportation over vast distances.

To make an imaginary illustration comes to you mind for the process of intermodal transport, for instance, an overseas shipment of luwak coffee beans that begins its plantation and "luwak" process in some arcadian area of Indonesia. After "luwak" process finished and the beans are ready to ship, those beans are packed into bags and then the bags are packed into container which gets loaded into a truck. This truck, moving through countryside roads among the trees, takes the freight to the nearest freight terminal that connects itself to the closest international port. Upon arrival, the container is shifted from the truck to a carriage without even touching the beans. And then the same process is repeated after the train arrives at the port—the container is loaded from the train carriage to a massive container ship. After crossing the oceans for several weeks, the ship finally arrives at a European Port. But the beans' journey does not end there, it goes with the same pattern of handling (moving through several modes) without the beans itself being touch until the container arrives to its distribution center in central Germany. Then, the beans are finally unloaded from the container and ready to be spread to various retailers. This narrative illustrates how multimodal freight transport works—transporting any goods with a specific kind of packaging (container or else) by using multiple transport modes, and most of all, ensuring efficiency and cost-effectiveness in the process.

Evaluating the movement of goods to increase the efficiency of transport pushes not only business entities, but scholars and academicians to do more research about logistic operation. The majority of transportation modes are matured separately and their competition in real life business tends to create transportation system which are segmented and unintegrated (Rodrigue, 2020). The market share of transportation in Europe is dominated by single-mode road transport (Wiegmans, 2014) and in Indonesia is more than 90% by road transport (Hermawan, 2017). These facts are some illustrations of how freight transport still depends on road transport globally. Building a multimodal network needs a huge capital and has a not-completely-fair-competition in the freight transport market due to existing power of major market player (Vanelslander, 2018), therefore, it is not as easy as comparing mathematical numbers between one plan to another for choosing between unimodal and multimodal transport.

The transportation stakeholders still consider the intermodal transport system because there is an undeniable economic advantage from the system, and modelling the system is one of the choices for analyzing the impact of the planned system (Van Duin and Ham, 1998). Each form of transportation can be used for what it does best because it has distinct advantages. Although trucks provide flexible door-to-door delivery, they may not be the most cost-effective option for exceptionally long distances. On the other hand, trains are limited by their tracks yet are good for moving huge loads across countries. Although ships may transport enormous quantities of cargo across oceans, they are naturally restricted to ports. Goods can be transported more cheaply by combining various modalities, which optimizes each leg of the journey in terms of cost, speed, and weight.

Another important motivator is the environmental aspect. Greener freight solutions are urgently needed as environmental degradation and carbon emissions become more of a worldwide problem. Intermodal transportation can greatly lower the carbon footprint of carrying products, particularly when it uses railroads, and a lot of projects has been done by focusing on implementing extra facility and service from a conventional multimodal system to something more environmental profitability (Rondinelli and Berry, 2000; Janic, 2011). Since trains are significantly more fuel-efficient than trucks, moving even a small amount of freight from the road to the rail can significantly reduce emissions.

With all potential benefits and expectations, however, intermodal freight transit has its share of difficulties, just like all other methods. A significant infrastructure investment is needed for seamless integration, including ports with specialized cranes, rail terminals that can handle enormous containers, and roads that can support container vehicles. Moreover, precise timing is required for a synchronized dance between various modes. The entire logistical chain may get disrupted if there are delays in one mode. It is difficult to dispute the appeal of intermodal freight transit, notwithstanding these difficulties. This method is more than just a logistical one, as the previous example of the luwak transportation process; it is a monument to human inventiveness and the will to improve, adapt, and get over obstacles. Recognizing that specific modes of transportation does not matter as much in a connected world as ours

2.2. Global Intermodal Freight Transport Trend

Historically, the freight transport business depended heavily on unimodal transport systems. A single method of transportation, such as a ship or a cart, would be used to convey goods, and that mode would be used to transport the goods all the way to the destination. However, as trade increased in volume and complexity and as cities, countries, and continents became more interconnected, a requirement evolved to effectively shift cargo from ships to trains, trucks, and even airplanes without noticeably increasing transit times or costs. *Intermodalism*, a system in which two or more modes of transportation are employed to move the same loading unit or vehicle in an integrated manner without having to handle the goods themselves during transfers, was born during this transition.

The intermodal trend started decades ago when the need for transporting freight overseas or over a longer distance than it had been done before increased. Nowadays, intermodal freight transport is seen as a solution for many transportation problems. One of the notable continuous projects of IFT has been done in Europe since 2014 as European Regional and Development Fund (ERDF), the Cohesion Fund (CF), and the Connection Europe Facility (CEF) splashed a sum of €1.1 billion for the period of 2014-2020 to many projects supporting intermodal freight transport development (European Court of Auditors, 2023). The fact that shares of rail freight and particularly of combined transport have increased and cut the unimodal's shares (Union Internationale des Chemins de fer and International Union for Road Combined Transport, 2020) cannot be ignored as the urge to use multimodal transport system is increasing despite its difficulty to be implemented.

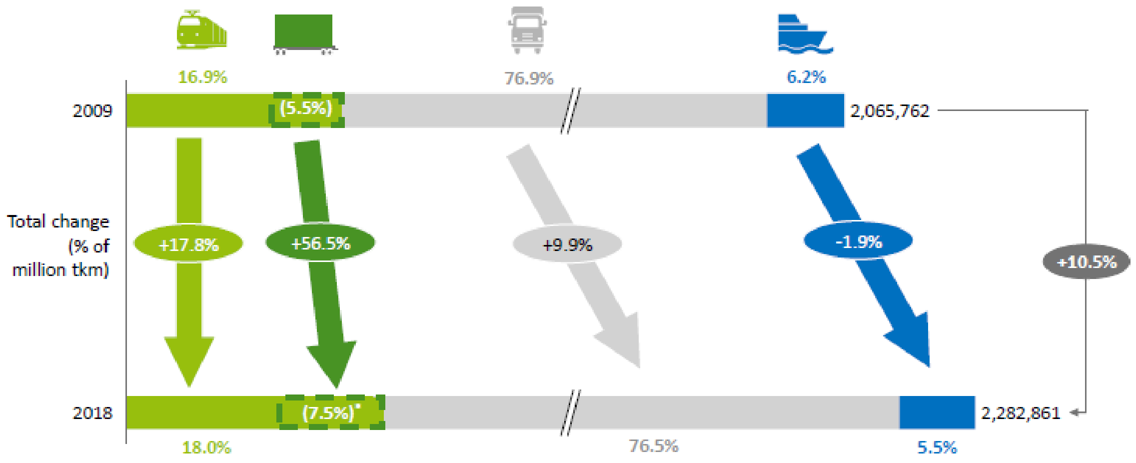

Figure 2-1 The Shares of Transportation Modes Freight in The Overall Modal Split in Europe

(Union Internationale des Chemins de fer and International Union for Road Combined Transport, 2020. The infographic was created by using the data from Eurostat)

EU Intermodal freight transport is not only seen as solution for separating road traffic load but also as a strategy for greening freight transport (European Court of Auditors, 2023). The way countries looking at transport system also has changed since global warming issue became more urgent to manage as the complexity within the process also increasing, and so, it is not only supposed to transport cargo from one place to another but also how the system can work as efficient as it can in the process. By study, road transport creates more emission than other transport modes (European Court of Auditors, 2023) and the graphic for emission comparison can be seen in Figure 2-2.

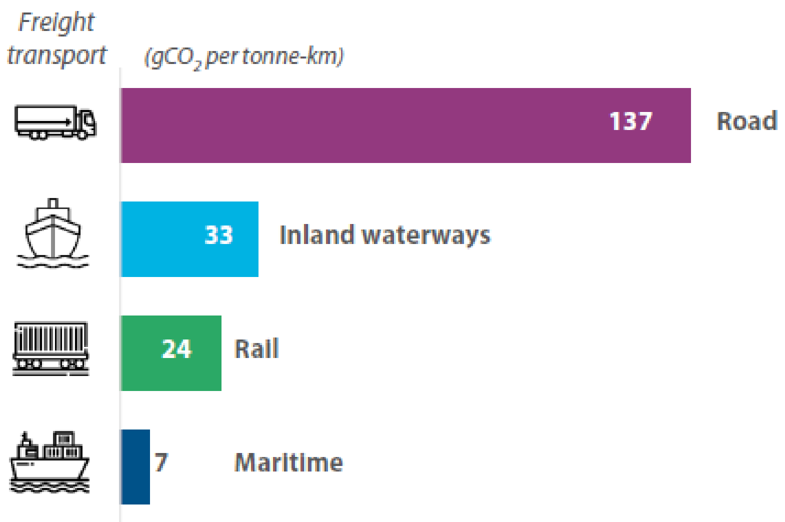

Figure 2-2 CO_2 Emissions by Mode of Freight Transport

(Source: European Court of Auditors, 2023)

Another example of huge multimodal project is China's Belt and Road Initiative program that announced in 2013 by Chinese President Xi Jinping. This project has a colossal scale, comprising both an overland Economic Belt and a 21st-century Maritime Silk Road in order to fashion after the ancient Silk Road (Lu *et al.*, 2018). This project does not specify the intermodal freight system as their main objective but rather uses IFT as part of connectivity system and infrastructure to achieve the project's goals. Before creating a new infrastructure and system, they looked for any existing integrated multimodal network in each country within the project's geographical scope before creating a new one (Schneider *et al.*, 2021). The fact that Chinese prefer multimodal network inside their huge project speculates the big benefit of IFT for transportation network of their new Silk Road. In regards of transportation system, this project will connect six major economic corridors by using and connecting multiple routes such as rail, roads, and waterways (Das, 2017). The illustration of China's Belt and Road Initiative program can be seen in Figure 2-3.

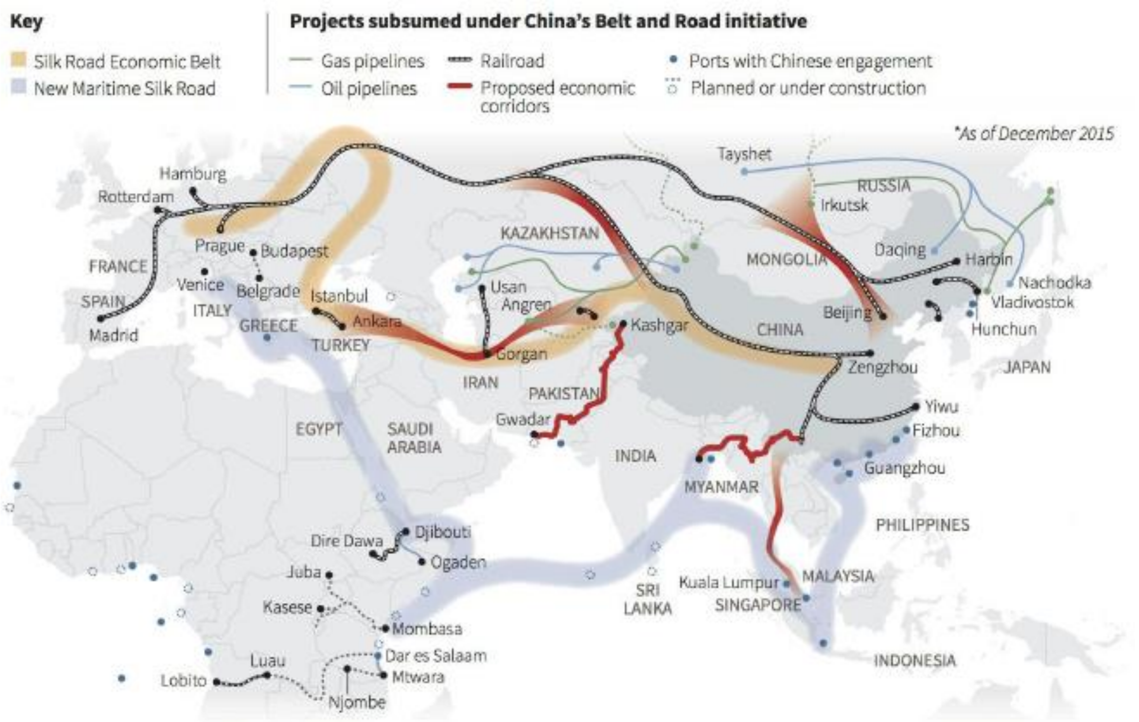

Figure 2-3 China's Belt and Road Initiative Project to Connect Major Economic Corridors by Using Multiple Modes

(Source: Lu *et al.*, 2018)

There are a lot more projects throughout the world that consist of IFT as either their main objective or part of the system to achieve their goals. Their main understanding of IFT is typically similar: to make the transportation system as efficient as possible. Despite all the benefits that IFT has, this system also has potential issues and obstacles. The following sub-chapter explains more about the positive and negative sides of IFT from some research that has been done and tries to construct all of reasons and impacts into SWOT analysis.

2.3. SWOT Analysis of Implementing IFT

The previous sub-chapter has explained about the importance of IFT in logistics business with some examples of projects related to it. Beside all the benefits and obstacles of implementing the IFT system, there are also some potential issues and fragility that should be considered before any entity decides to do that. This sub-chapter tries to analyze them all by using SWOT (strength, weakness, opportunity, and threat) from lot of researches regarding the IFT. This analysis should illustrate the circumstances of implementing IFT in transportation systems. The SWOT analysis in this sub-chapter is based on four different researches in four different places: Belgium's BRAIN-TRAINS (Vanelslander, 2018), Interreg Central Europe (TRANS TRITIA, 2020), Cape Brenton Island (Amin, Yan and Morris, 2018), Pacific Northwest, USA (Vergara, Ghane-Ezabadi and Rahanjam, 2015) and Romania (Scarişoreanu and Ghiculescu, 2023). The summarize of findings about IFT systems in those researches can be found in Table 2-1 and Table 2-2.

Table 2-1 Strength and Weakness of Intermodal Freight Transport Based on Researches

Strength	Weakness
• Reduces costs of freight transport and carbon emissions over long distance transport. • Triggers new investments. • Takes advantage of the strength of such different modes. Logistic planners can maximize the efficiency of the freight transport system due to additional alternative choice. • Pushed the market to get a more skilled labor force. • Reduces road congestion. • Better modal split. • Higher competition in freight transport and logistics market. • Triggers stronger containerization and other reloading technologies development along with their standardization systems. • Reduces external transport costs.	• Needs more skilled labor force. • Due to extra handling, the transport time gets slower than unimodal transport. • Railway maintenance and repair works. • High capital cost. • Network access is weaker compared to road transport. • Opportunity cost as a result of reliability issues and extended journey times. • Longer lead times until a new service is operational. • Choosing appropriate pricing methods and subsidies programs might be difficult.

(Source: Vergara, Ghane-Ezabadi and Rahanjam, 2015; Amin, Yan and Morris, 2018; Vanelslander, 2018; TRANS TRITIA, 2020; Scarişoreanu and Ghiculescu, 2023)

Table 2-2 Opportunity and Threat of Intermodal Freight Transport Based on Researches

Opportunity	Threat
• Potential other transportation business from any remote/isolated areas. • Economic growth. • Can tackle the high fuel price issue for truck. • The development of multimodal transport system to support the reduction of external transport cost. • Infrastructure growth for various kinds of transportation. • Triggers modern technology evolution and growth, including telematics and information technologies. • Encouraging the industrial sector to place manufacturing facilities close to intermodal terminals. • Increased technology investments in R&D have a good impact on rail, such as standardizing technologies and fostering interoperability. • When GDP increases, there is a beneficial impact on the demand for mobility.	• Barriers to interoperability: at the infrastructure, regulatory, and actor levels. • A lack of qualified employees and the aging of current employees. • Number and quality of supporting infrastructures. • Lack of economies of scale. • Absence of a current national multimodal transportation policy. • Government financing and assistance for the development of transportation modalities are limited. • Low commercial speed growth in the rail freight transport sector. • Long-term projects carry financial risk (the risk of exceeding the project budget). • Labor and employee costs.

(Source: Vergara, Ghane-Ezabadi and Rahanjam, 2015; Amin, Yan and Morris, 2018; Vanelslander, 2018; TRANS TRITIA, 2020; Scarişoreanu and Ghiculescu, 2023)

Chapter 3. Theoretical Review

The integration of port connectivity to its hinterland plays a pivotal role nowadays due to infrastructural and technological developments. The traditional approach, which describes port demand as a captive traffic rather than volatile traffic, is no longer relevant (Cuadrado, Frasquet and Cervera, 2004). Moreover, the volatile traffic concept creates a broader manifestation of port development project by enhancing its scope to port's hinterland rather than just focusing within the boundary of the port. In terms of hinterland, the influence of journey time and service quality factors have progressively influenced the paradigm to determine ports' hinterlands, other than the conventional factors such as availability and cost (United Nations, 2010). Thus, before applying the concept of intermodal freight transport and travel time analysis into Port of Tanjung Emas' hinterland, it is important to understand the theoretical approach behind all of those models and how these two models can connect to each other for analyzing the transportation conditions.

3.1. Intermodal Freight Transport (IFT)

The transportation from one point to another has its own characteristics and properties, and it can be translated as "cost" to point a single variable that can justify all of its complex variables behind it. However, the optimization of hinterland transportation systems remains a complex challenge by virtue of numerous factors, including geographical constraints, infrastructure limitations, regulatory frameworks, evolving market dynamics, and other technical issue within this matter. One of the best methods to optimize the port-hinterland connectivity is by combining all of the available modes within its area and comparing the network from all those modes to find out the most efficient hinterland connection system. Here comes the *Intermodal Freight Transport Model* to analyze this matter.

Intermodal freight transport, the art of moving goods via a blend of sea, air, rail, and road without directly handling the cargo during transitions, isn't new. IFT has been discussed for decades, and the benefit of implementing this approach is still expanding due to technological developments. There are a lot of definitions for intermodal freight transport, with a pretty similar conclusion between them. One of the most used definitions of IFT is the statement from the European Conference of Transport Ministers in 1997 (Rushton, Croucher and Baker, 2014, p. 417): "the movement of goods in one and the same loading unit or vehicle, which use successively several modes of transport without handling of the goods themselves in changing modes". *The Handbook of Logistics and Distribution Management: Understanding the Supply*

Chain (Rushton, Croucher and Baker, 2014) suggests that railways play a key role in intermodal freight transport, not only for transporting containers but also bulk freight. In reality, that statement can be proven in a lot of major projects for intermodal transport, where rail transport is their main core line and surrounded by other lines of modes to support it for several types of transport networks.

In terms of definition and practice, intermodal and multimodal transportation have a huge similarity with a slight difference between them. (Rodrigue, 2020) in his book "The Geography of Transport System" divides *intermodalism*—a transport system that involves at least two different modes in a trip from an origin to a destination along an integrated transportation network—into three components:

- Intermodal transportation. The moving process of people or goods from one place to another by using various forms of transportation. Each carrier issues its own contract or ticket for freight and passengers, respectively. Transfers between modes of transportation frequently occur in a terminal that was created particularly for that purpose.
- Multimodal transportation. The moving process of people or goods between an origin and a destination by using various forms of transportation and one ticket (for people) or contract (freight). Although it is technically the same as intermodal transportation, this mode of transport has evolved and calls for a deeper level of cooperation between the many players/actors, including carriers and terminal operators.
- Transmodal transportation. the movement of freight or passengers inside a single mode of transportation. Although intermodal operations (such as ship to dockside to ship) are frequently necessary and pure transmodal transit is uncommon, the goal is to maintain continuity within the same modal network.

Although they seem to be pretty similar, the differences between intermodal and multimodal transportation are actually quite significant. Multimodal transportation is not always the most efficient or sustainable option, despite the fact that it may appear that way because there are fewer transaction costs for the user. A multimodal transport service provider will be prone to using its facilities and routes, which are not necessarily the most practical, during the transit process. A third-party logistics provider's (3PL) primary goal is to make the most of its resources, which may run counter to the interests of its clients. The complexity of contract for freight is much higher than ticket for passenger, most probably because the common scheme of freight transport divides the contract for each mode, either because of insurance matter, 3PL capability, different interest between 3PL and freight owner, or else.

Transmodal transportation means connecting various pieces of the same mode between an origin and a destination. It strives to accommodate freight or passenger transport with several modal services on the same network. In transmodal transportation contract, there is no specific statement or rule about being a single or separate contract in order to run the transportation process. Transmodal transportation is a frequent method in air travel because it is simple for customers to book a ticket from one place to another, even if it requires passing via a different airport and using a different airline. Because of the extensive amount of handling necessary for freight transportation, switching load units within the same mode is typically more difficult, making transmodalism more difficult than the previous two methods. The illustration of differences between intermodal, multimodal and transmodal transportation system can be seen in Figure 3-1.

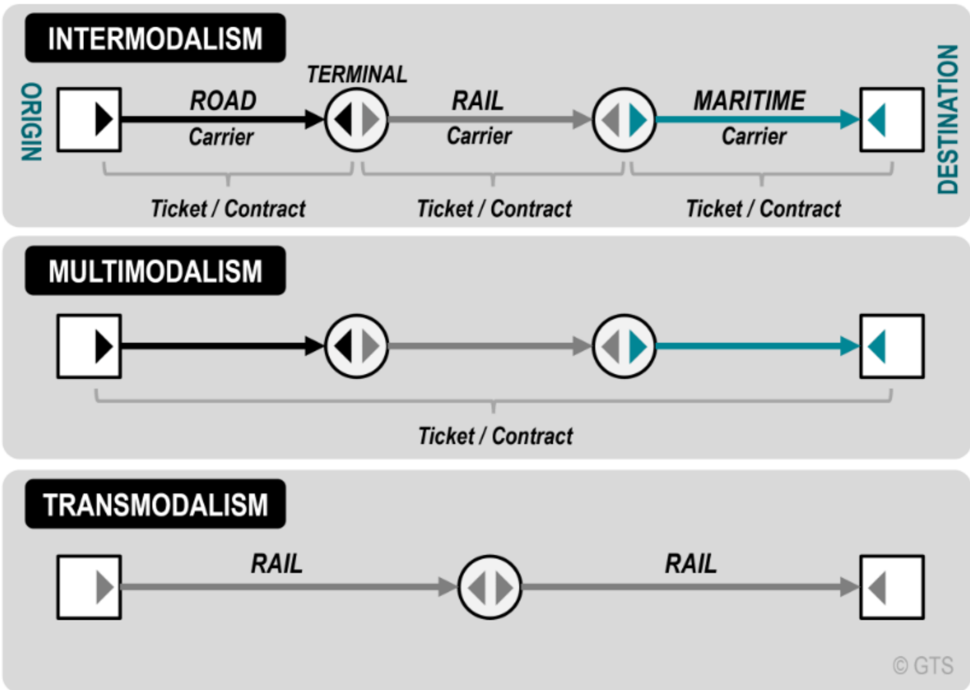

Figure 3-1 An Illustration to Differentiate Intermodal, Multimodal, and Transmodal Transportation System
(Source: Rodrigue, 2017)

The intermodal freight transport has some combination of modes to be implemented but in this research we just focus on land connectivity of truck and train to port. As shown in Figure 3-2 below, the typical concept of IFT has railroad (or inland water transport) as its main line to connect between two main terminals, while the other modes (such as road transport) support by gathering or spreading the goods. This simple concept can be enhanced by adding more main terminals to make it more complex but the idea of IFT itself is well-described by just using that the picture above. (Wiegmans and Konings, 2013) also states that the basic concept is not only worked for multi-source producers and multi-destination customers, but also single-source producer or single-destination customer.

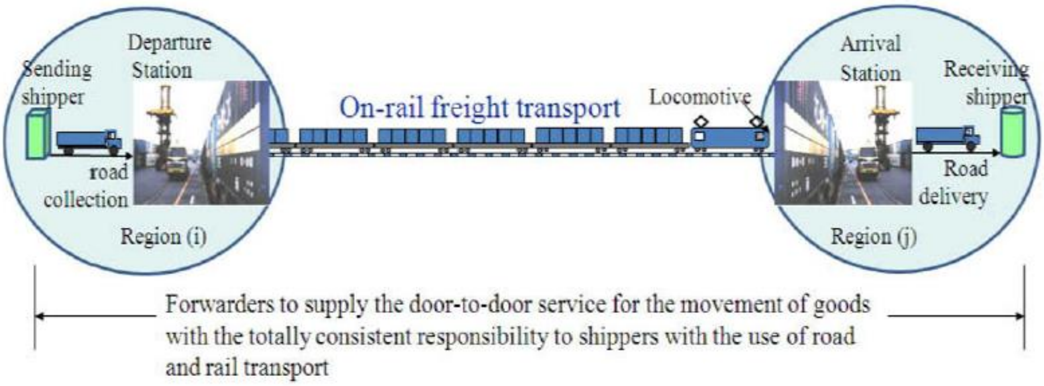

Figure 3-2 A Typical Road-Rail IFT Model
(Source: Li *et al.*, 2014)

Furthermore, (Li *et al.*, 2014) explains the basic procedure of road-rail IFT as follows.

1. Road haulage for collecting relevant containers or freights from sending shippers to the departure main terminal.
2. Transshipments of containers or freights from truck onto freight train.
3. On-rail transport across a number of rail corridors in the railway network, or possibly with some necessary train operations on the way, to the arrival main terminal.
4. Re-transshipments of containers or freights from freight train to truck.
5. Delivering containers or freights to the receiving shippers by road haulage.

In this research, the elements that are considered would be described as follows: two or more different transport modes are deployed to carry out the goods or freights; the main haulage is carried by rail; road vehicles are able to transport the goods or freights outside main haulage, or should be described as initial and final legs for the movement of goods or freight; the cost to transport the goods or freight for each type of modes are the same; and the ultimate origin or destination of the transport network is Port of Tanjung Emas, Indonesia. The theoretical design of the transport network itself will be explained in the next sub-chapter.

As it is mentioned in sub-chapter 2.1, the multimodal system has a lot of uncertainty in the process of making it out of thin air. (Van Duin and Ham, 1998) has created a framework of planning multimodal transport which has a huge connection to the profitability of the network system. Mainly, there are the stages of modelling approach according to this study—linear programming model, cost analysis model, and simulation model. Those models are implemented in various stages of planning, with linear programming model comes to the wider geographical scope and the others come to the narrower scope. This approach separates the technical implementation of multimodal system from its feasibility and profitability. The stages of modelling approach can be seen in Figure 3-3.

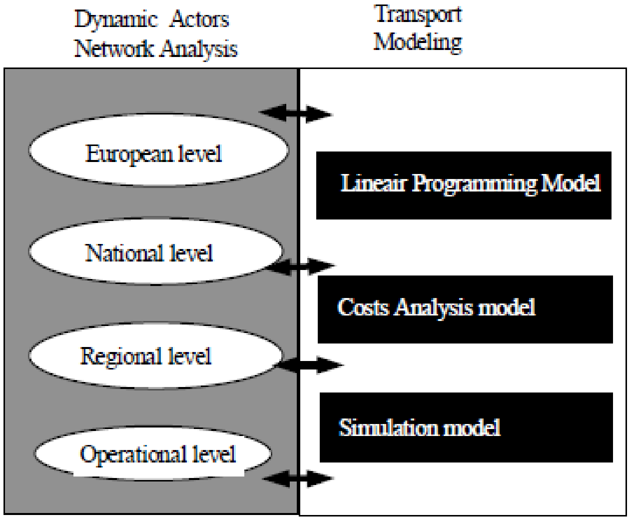

Figure 3-3 Three Stages Modelling Approach for Implementing Intermodal Transport System
(Source: Van Duin and Ham, 1998)

This research will focus on the first stage—linear programming model—as the system is created out of thin air in its geographical scope. This stage focuses on the actors of the system, how the system will be implemented in the area, finding the best choice of potential intermodal terminal, and how the multimodal transport system will enhance the existing network system. Because all the stages are somehow interrelated to each other, this research also talks about the cost analysis, which is the most interesting issue from a business entity perspective. Transportation entrepreneur tends to focus merely on profitability issue on the planning stage of multimodal system because the small profit margins in the business (Van Duin and Ham, 1998). Even though this research also does the cost analysis model, the linear programming model is still the main core of analysis, and it is only a small portion of cost analysis that has been done in this research. The cost analysis part is done in order to compare the result between scenarios that are being implemented in this research.

3.2. Isochrones Model for Estimating the Travel Time

Understanding travel times and the accessibility of certain locations is essential for efficient transportation planning, supply-chain design, urban planning, and location-based services in the fast-paced world of today. Knowing how far one can go in a certain amount of time from a particular location can offer important insights into the effectiveness and connectivity of a geographical area. The isochrone model, which creates isochrones maps showing areas reachable within particular travel times, is a potent tool for achieving this. In Greek, 'iso' has a meaning of 'similar" and 'chronos' means time; hence, isochrone means similar time. In academic terms, isochrone is a display or a map of either points, lines or areas which estimate a duration or period of travel from a specific location within a specified time (Van Den Berg *et al.*, 2018). These maps are essential for studying transportation systems, assessing the effects of urban growth, and identifying places where businesses and public services can be found. The isochrone map can be essential to analyze catchment area and reachability of a certain time-parametrized network, such as road network and its connection to the traffic (Efentakis *et al.*, 2013).

Several considerations must be made in order to build an isochrone map:

1. Origin: The model needs a certain starting point or origin. It may be a specific address, a famous location, or any geographic coordinate.
2. Transportation Network: A thorough depiction of the local transportation system is required. Typically, this includes pedestrian walkways, public transportation lines, and road networks.
3. Calculating Move Time: It is necessary to determine the amount of time required to travel from one site in the network to another. This calculator considers a number of variables, including walking distances, road conditions, traffic congestion, speed limits, and public transportation timetables.
4. Time Intervals: In order to produce the isochrone lines, the desired time intervals or increments must be determined. For instance, intervals might be 15, 30 minutes, or 1 hour, depending on the situation and case that the map intends to answer.

The time-dependent variable can be various in travel time model depending on what kind of transportation and situation that the model wants to analyze. For example, freight travel time can have an input of handling time and transit time while passenger travel time will only focus on transit time. The advanced travel time model can also add multiple transit points and modes to be analyzed in order to get the most efficient route of transportation. The development of travel time analysis by using isochrone model has changed from a simple presentation of model into a more user-friendly illustration such as using schematic isochrones (Forsch *et al.*, 2021) in order to give a better understanding of the model's result.

3.3. Transport Network Model

Delivering the shipment—whether it be people or goods—from the point of origin to the destination is the primary goal of transportation. The transportation network mostly depends on the problem that has to be solved in terms of transportation; it may be as straightforward as making the network itself available or as complex as conducting advanced analysis to increase its efficiency. The structure of the supply chain and the limits they impose on the other supply chain drivers' ability to either lower supply chain costs or improve responsiveness are determined by network design decisions, which have a substantial impact on performance (Chopra and Meindl, 2013).

The basic mathematical model for service network design uses the form of deterministic, fixed cost, capacitated, multicommodity network design formulations (Crainic and Kim, 2007). In general, we can divide the network design into two kinds: static and time-dependent service networks (Crainic and Kim, 2007). The most obvious thing that can distinguish those formulations is the variation of demand. While static formulation assumes that the demand is the same within the time period of the model, the other tends to make demand more dynamic inside the formulation and tries to make the model represents the variation of movements and schedules due to the uncertainty of demand.

3.3.1. General Transportation Problem

The transportation problem usually comes up when planning for the distribution of goods and services from various supply sites (origin) to various demand areas (destination). In this research, we use linear programming problems in order to demonstrate the general transportation model, or so-called *network flow* problems. This method is widely used to solve the network problems for transportation model (Anderson *et al.*, 2016). The general transportation model is as follows:

$$\text{Min} \quad \sum_i \sum_j c_{ij} x_{ij}$$

$$s.t.$$

$$\sum_j x_{ij} = s_i \qquad i = 1, 2, \ldots, m$$

$$\sum_i x_{ij} = d_j \qquad j = 1, 2, \ldots, n$$

$$x_{ij} \geq 0 \qquad \text{for all } i \text{ and } j \qquad (1)$$

Notations:

Min	minimum value for the variable equation
i, j	origin and destination of the transportation services
m	number of origin
n	number of destination
s	supply
d	demand
x_{ij}	total amount of goods from i to j
x_{ji}	total amount of goods from j to i

The constraint from the equation above is the minimum constraints to solve the general transportation equation. We can add more constraint such as for limiting the capacity for every route ($x_{ij} \leq M_{ij}$, with M as route capacity) or limiting the capacity of the destination ($x_{ij} \leq N_{ij}$, with N as destination capacity). The figure below illustrates the general transportation model as nodes and arcs.

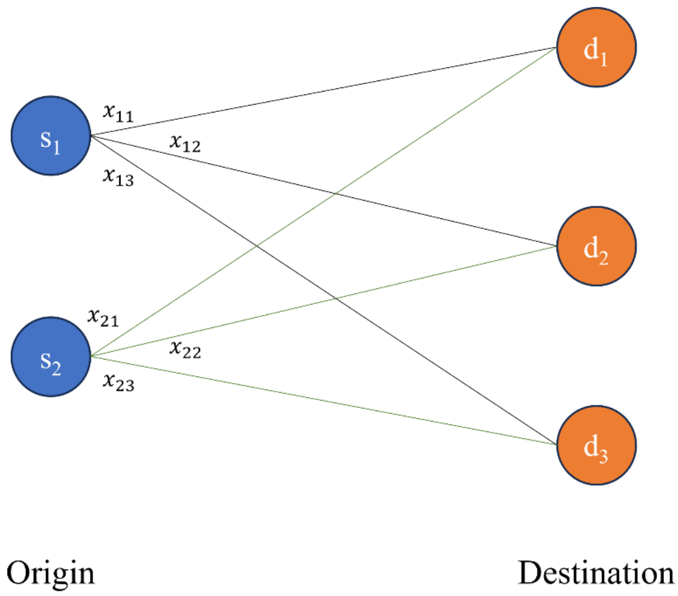

Figure 3-4 The Illustration of General Transportation Problem

3.3.2. Transshipment/Intermediary Problem

The transshipment/intermediary problem is a more complex problem in network transport problems than general transportation problem. The major difference between general transportation and transshipment problems is intermediary nodes between origin and destination in transshipment problem. The objective of the transshipment problem is to decide the number of units that shall be transferred within each arc so that all demands are satisfied by using the lowest cost available of the possibilities. The transshipment can also be solved by using the linear programming model, which is developed from the core general transportation problem, as can be seen in the following formula:

$$\text{Min} \quad \sum_{i}\sum_{j} c_{ij}x_{ij}$$

$$s.t.$$

$$\sum_{j} x_{ij} - \sum x_{ji} = s_i \qquad \text{for each origin } i$$

$$\sum_{j} x_{ij} - \sum x_{ji} = 0 \qquad \text{for each intermediary node } i$$

$$\sum_{j} x_{ij} - \sum x_{ji} = -d_i \qquad \text{for each destination } i$$

$$x_{ij} \geq 0 \qquad \text{for all } i \text{ and } j \tag{2}$$

Notations:

Min	minimum value for the variable equation
i, j	origin and destination of the transportation services
m	number of origin
n	number of destination
s	supply
d	demand
x_{ij}	total amount of goods from i to j
x_{ji}	total amount of goods from j to i

The modifications for linear programming model in transshipment problem are identical to the modifications required for the transportation problem (by limiting the capacity for each arc and destination). Figure 3-5 below illustrates the transshipment problem as nodes and arcs. This transshipment problem is a significant model for network problem because all the origins and destinations can perform or function in any direction, thus, this simulation is a good tool to illustrate how to reduce the total cost of transport operation in a network (Khurana, 2015). Moreover, the cost variable in this model can be used to illustrate all possible impact variables of doing the business such as environmental cost (Januardi, Ramdhani and Harnaningrum, 2020) and calculating the optimum route and transport mode (Xu et al., 2017; Li et al., 2023).

The dynamic model of this method can also serve as a simulation of problem with impaired flow, enhanced flow, and capacitated flow (Khurana, 2015). This method has a wide range of applications and can be done with various softwares. Although this method comes in handy for many transportation problems, the optimum solution from this method will be useful and on-point if it is done by using a comprehensive analysis for every variable within.

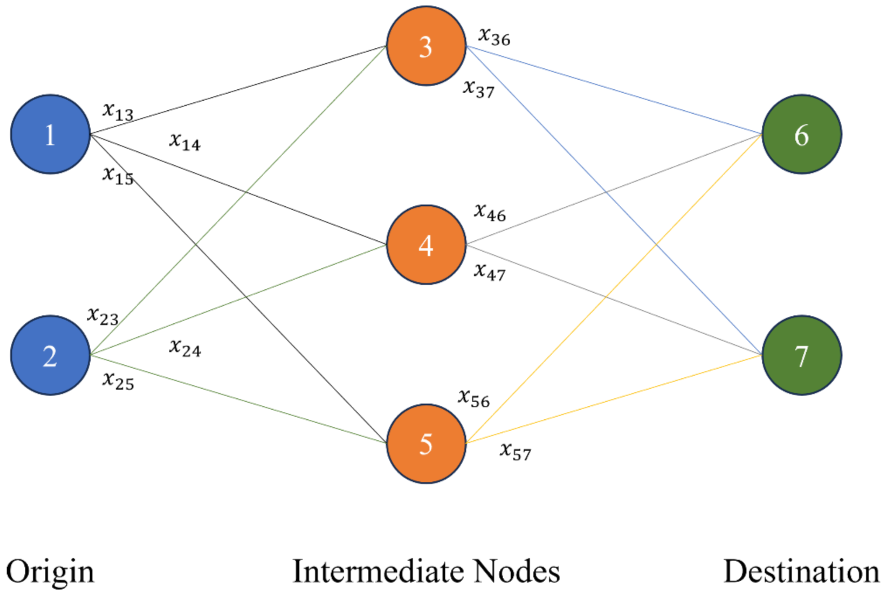

Figure 3-5 The Illustration of Transshipment Problem

Chapter 4. General Review of Tanjung Emas Port

The Port of Tanjung Emas, located in Central Java Province, Indonesia, is one of the largest operating ports in Indonesia. Situated in the city of Semarang, which is the capital city of Central Java Province, it serves as a crucial gateway for national and international trade, connecting Central Java Province to the marketplace outside Java Island. The Port of Tanjung Emas plays a key role in local and national economic growth in addition to its function as a trade facilitation hub. It acts as a crucial economic hub, luring companies and industries to the neighborhood. The port fosters local enterprises, creates jobs, and supports the expansion of the maritime and logistics industries. With the port's expansion taking its place, Port of Tanjung Emas will rely much on container cargo as their main type of goods in the future. In this chapter, we review the operation condition and performance of Tanjung Emas Port and also the connectivity condition to its hinterland.

4.1. Port of Tanjung Emas Existing Operation and Port Performance

4.1.1. Port's Location

Tanjung Emas Port is a seaport located in Semarang City, Central Java Province, Indonesia. The geographic coordinate of this port is 6°56'40.27" South dan 110°25'25.99" East. The port location within the border of Central Java Province can be seen in the figure below.

Figure 4-1 Port of Tanjung Emas Location

(Source: Google Earth, 2023)

4.1.2. Port Operational Data

The Port of Tanjung Emas serves three kinds of commodities in its daily port operation: container, oil and gas, and other goods, which the later commodity is gradually being converted into containers due to simpler and more efficient port operation. In 2021, the total throughput of containers in Tanjung Emas Port was around 850 thousand TEU, which is dominated by international trade. Based on the data from Port Authority of Tanjung Emas, the container size ration in that port is around 3:2 for 20 feet and 40 feet containers respectively in 2021. The container throughput number increases every year due to massive containerization process and increasing population. The increase of container throughput is forecasted to be continue because of the development of industrial zones across PoTE hinterland (Ministry of Transportation, 2022). The detail of Tanjung Emas' throughput for all commodities can be seen in the table below.

Table 4-1 Throughput of Tanjung Emas Port from 2016 to 2021

Year	Container		Oil & Gas		Others	
	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming
2016	299,023	313,675	4,942,570	738,047	1,805,460	0
2017	295,927	350,026	5,411,651	357,063	1,959,988	0
2018	309,981	344,293	4,899,299	316,237	1,821,700	0
2019	296,432	361,871	4,331,307	228,721	2,042,182	0
2020	377,283	357,899	4,066,839	226,013	2,213,301	0
2021	392,459	463,535	4,240,472	123,828	-	-

(Source: Port Authority of Tanjung Emas, 2022)

Table 4-2 Details of Container Throughput in Port of Tanjung Emas from 2016 to 2021

Year	International		National	
	Outgoing	Incoming	Outgoing	Incoming
2016	307,407	291,759	6,268	7,264
2017	330,885	280,259	19,141	15,668
2018	330,857	296,902	13,436	13,079
2019	340,494	275,531	21,377	20,901
2020	327,818	347,401	30,081	29,882
2021	424,140	357,771	39,395	34,688

(Source: Port Authority of Tanjung Emas, 2022)

4.2. Port of Tanjung Emas Hinterland

Determining port hinterland is a crucial part for planning its network transport. Based on the origin-destination analysis, Port of Tanjung Emas hinterland spreads mainly within Central Java Province, with minor demand from Yogyakarta Province and other minor parts of demand come from west and east side of the Central Java Province (Ministry of Transportation, 2022), with Semarang City as the highest demand location. The mentioned study concludes that Central Java and Yogyakarta Provinces significantly influence Port of Tanjung Emas hinterland. Hence, this study will focus on the demand from both provinces in order to determine the conditions of Tanjung Emas' connectivity to its hinterland. The hinterland of Tanjung Emas Port can be seen in Figure 7-2.

Figure 4-2 Port of Tanjung Emas' Hinterland (bordered within red line)

(Source: Google Earth, 2023)

4.3. Condition of Port Connectivity to Its Hinterland

Semarang City is one of the biggest cities in Indonesia and resides a great amount of population. The business activity in this city is pretty intense, and the existence of Tanjung Emas Port within the city also creates a huge traffic load which results in congestion across the city and the surrounding area (Napitupulu, Jinca and Riyanto, 2022). Although it is suggested that the main factor that effect Semarang's traffic condition are geometric condition of the road as well as intersections (Napitupulu, Jinca and Riyanto, 2022), but the amount of vehicle itself are so high which makes the road overpopulated with all kinds of vehicles. This circumstance pushes the government to make solution for the oversaturated transport network. One of the proposed solutions for tackling the transport network issue is by optimizing intermodal transport for both freights and passengers (100 Resilient Cities, 2016).

As for Port of Tanjung Emas, the main mode to connect this port to its hinterland is by using road transport (Ministry of Transportation, 2022). The circumstance of depending too much on road transport happens not only in PoTE hinterland but also across Indonesia, with more than 80% of freight transport dependent on road transport (Hermawan, 2017). Although PoTE has much dependency on road transport, it has an enormous potential of using railway to transport the freight because the rail infrastructures already exist and scattered across its hinterland. The national class road and railways networks within PoTE hinterland can be seen in Figure 4-3 and Figure 4-4 respectively.

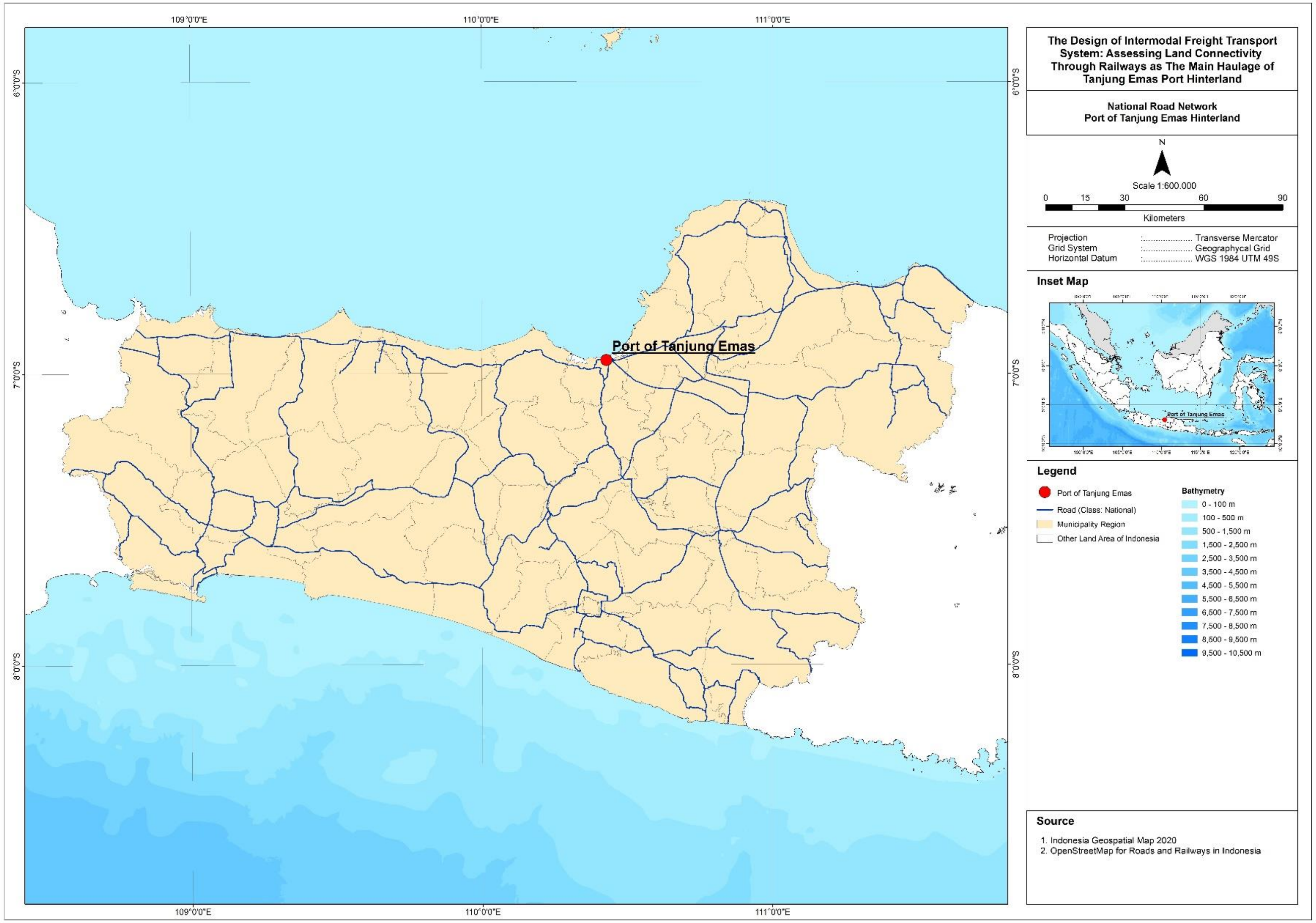

Figure 4-3 National Class Road Network in PoTE Hinterland

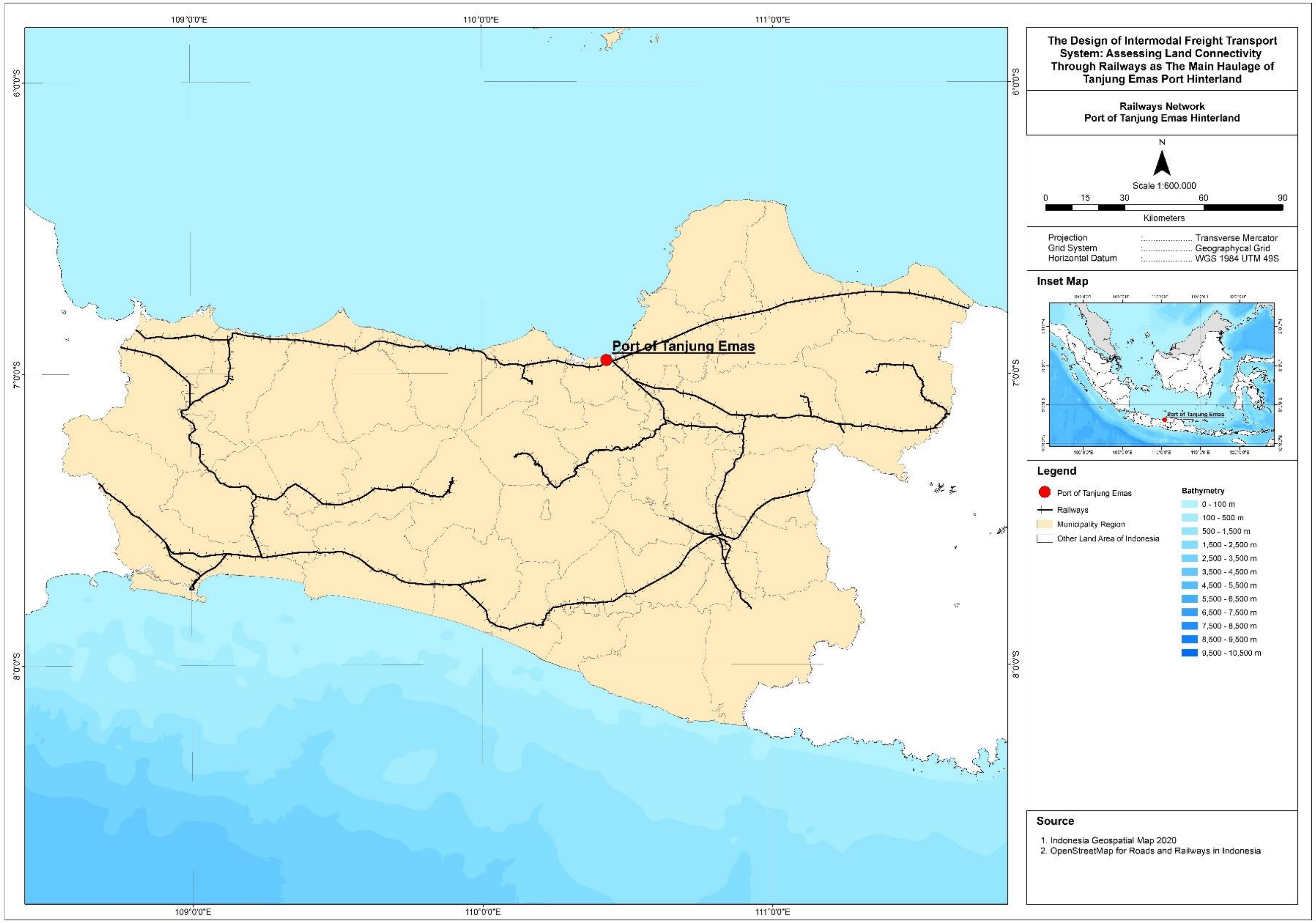

Figure 4-4 Railways Network in PoTE Hinterland

Chapter 5. Conceptual Framework and Hypothesis Development

In Chapter 2 and 3, we discussed the importance of Intermodal Freight Transport and its benefits to the logistics system. Furthermore, this chapter explains about the previous research which focused on IFT and its framework to conclude the research. A conceptual framework functions fundamentally as a map that delineates the area of study. The research is grounded and directionally accurate because it provides a visual or narrative depiction that combines theory and practice. Having a strong conceptual framework for a subject as complex as intermodal freight transport is not only advantageous—it is necessary. This chapter will provide ample theoretical framework of this research, explaining the general condition of freight transport in Indonesia, especially in the region around geographic scope of this study, then the explanation continue towards the implementation of IFT in a transportation network and how to calculate the efficient system based on the planned model from perspectives of several previous research. This chapter will describe the most suitable method to be used in order to analyze the problem and determine the method to illustrate the impact of planned IFT system.

5.1. General Condition of Freight Transport

The freight transport in Indonesia has vast and unique properties because of its interesting geographic landscape of archipelago. Road, rail, aviation, and sea modes of freight transportations are all used in Indonesia. Due to the size and geology of the nation, some places significantly favor one mode of transportation over another. Although Indonesia has a huge water area, including rivers and seas, but the majority of freight transports are done by land transport. The market share of freight transport in Indonesia is dominated by road transport with 90.34% of total freight transport per year (Hermawan, 2017). This circumstance happens mainly because of economic concentration of Indonesia which happened in one big island of Indonesia, Java Island. The domination of road transport can be a huge concern for Indonesia government because in recent years, the gross domestic product (GDP) value of Indonesia has significantly increased (except 2020 when the global pandemic stroked) (BPS - Statistics Indonesia, 2023). According to Rodrigue (2020), GDP growth has significant correlation with container trade growth, which implies the freight traffic condition in a certain country. By associating the mentioned theory and GDP trend that happened in Indonesia, there is a substantial believe that freight transport business will be busier in coming years in Indonesia. The comparison of container throughput and GDP of Indonesia can be seen in Figure 5-1.

Figure 5-1 Comparison of Indonesia's Container Throughput and Gross Domestic Product in 2012-2021

(Source: UNCTAD, 2021; BPS - Statistics Indonesia, 2023)

As it can be seen in Figure 5-1, taking aside its fluctuation, the container throughput in Indonesia tend to raise if there is no sudden global event that impact the economy of this country such as global recession in 2015 and COVID-19 pandemic in 2019-2021. The domestic containers still dominated the market with 53% of total container volume in Indonesia (Nur, Achmadi and Mercy, 2020). The international containers, either export or import, mostly use the international hub, such as Tanjung Priok, Tanjung Perak, and Belawan, to accommodate the transport service.

In Java Island, which are the busiest island of Indonesia and where the majority of business happened, there are several ports which eligible to transport both national and international containers. The northern side of this island is much busier than the south coast. On the north coast of Java, there are Tanjung Priok, Tanjung Perak, Tanjung Emas, and Patimban, which the latest name is the newest addition of international port cluster of Indonesia. Port of Tanjung Priok has the biggest throughput of them all and even in Indonesia, serving more than 7.2 TEUs in 2022 (Lloyd's List Intelligence, 2023a). Port of Tanjung Perak also has significant number of container throughput, which is 3.9 TEUs in 2022 (Lloyd's List Intelligence, 2023b). Both operating ports are considered gargantuan to Port of Tanjung Perak in terms of throughput volume. Indonesia government wants to divide the monstrous demand of Tanjung Priok by building a new port in West Java Province called Port of Patimban. Hence, the competition between those ports in the north coast of Indonesia is mildly higher than before Port of Patimban exist. The Port of Patimban has been operating since 2021 but is still in its early phase of development. This port is planned to be the biggest port in Indonesia which will have a container capacity of 7.5 million TEUs per year (Arkyasa, 2023). Although the competition from other ports in Northern part of Java is high, it will be ignored in this research due to the main focus of implementing the intermodal accessibility with the existing throughput of Tanjung Emas port.

5.2. Calculating The Total Moving Time by Travel Time Model

Sub-chapter 3.2 already explained about the basic knowledge of isochrone model in regard to illustration of travel time model. An isochrone model shows the contour of time needed to move from one point to any random point within the boundary. The main problem of a contemporary isochrone model is that the model assumes a static velocity in order to calculate the travel time so any significant variation happened between each movement will be ignored (Van Den Berg *et al.*, 2018). Hence, the calculation only provides default forecast through the analysis of static movement speed. Although dynamic isochrone model already exist, static isochrone model with, is still be used in many fields of business for investment decisions or interpretations, such as transport planning and accessibility analysis (Tenkanen *et al.*, 2016).

A transportation network's accessibility is determined by how easily people, commodities, or services can get there and what services they need (Weibull, 1980; Geurs and van Wee, 2004). This analysis can be used in various kinds of research such as analyzing the health-related accessibility in an urban environment (Tenkanen *et al.*, 2016), time accessibility of public transport (O'Sullivan, Morrison and Shearer, 2000; Bielecka, 2013), accessibility of certain location or facility (Kolcsár and Szilassi, 2018), scoring accessibility and inequality for urban areas (Biazzo, Monechi and Loreto, 2019), and intermodal transport analysis (Forsch *et al.*, 2021). Some of those researches also combined the travel time model with other methods in order to get the best result of analysis. Travel Time Model is derived from Geographic Information Subject (GIS) subject, hence, knowledge about GIS and its processing software should be adequate in order to get the best result. An example of isochrone model which is done by another research can be seen in Figure 5-2.

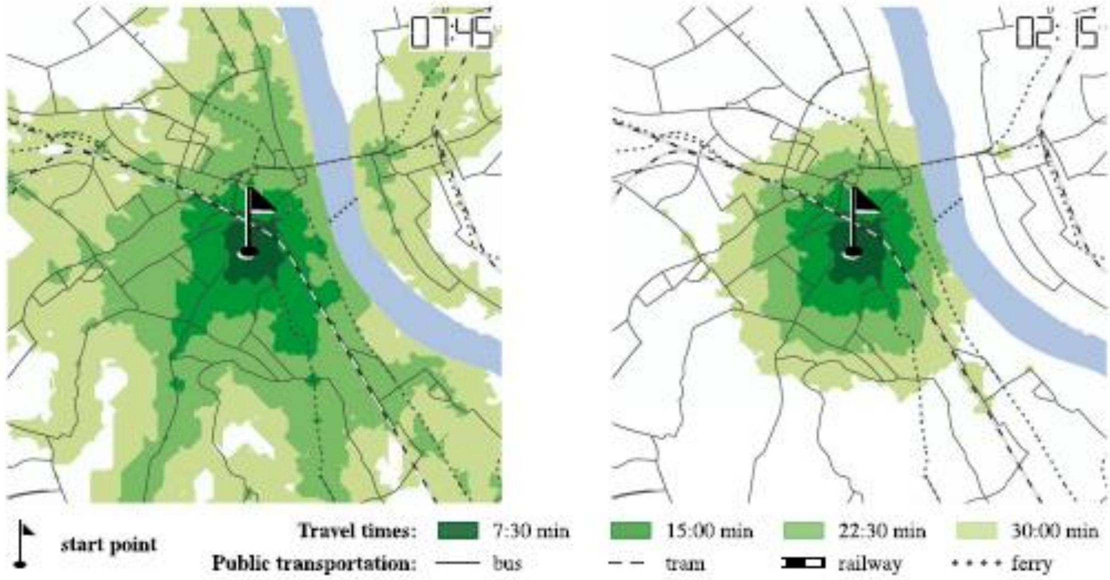

Figure 5-2 Example of Travel Time Model for Public Transportation which Shows the Accessibility of Transport Network in an Urban Area Starting from One Specific Point for Different Start Times

(Source: Forsch *et al.*, 2021)

Van Den Berg *et al.* (2018) shows the general workflow to create an isochrone map in nine steps, as can be seen in Figure 5-3. The first step is to gather or create the network dataset which includes all pathways of modes needed for the model (1). Secondly, the calculation variables for each part of the pathways need to be inserted and/or calculated into the dataset, including length, velocity, and partial travel time (2). By using the calculated dataset, which is created in step 2, the travel time from one point to another can be extracted from the model (3). After the default environment for the model is created, the process will move further into preparing *population dataset*. This dataset is a collective of node points for modeling purposes (4). Both datasets (network and population datasets) now shall be combined (5) and the travel time between nodes can be extracted depending on the research/model purpose (6). The remaining steps are about visualizing the result which overlay the result to the map (7), adding interactive elements (8), and evaluating the isochrone map (9). These steps are the basic steps to create an isochrone map that can be done by using various softwares such as ArcMap and Qgis. Every time variable shall be calculated in step 1, including the movement time (depending on velocity), handling time, transit time, etc. The visualization process depends on how the researcher or modeler wants to illustrate and the result testing part is a process of validating and verifying the result. The result can be compared to many sources such as field surveys, other related researches, google maps, etc. With a series of contours as the result of travel time model, this study can further analyze how different modes can affect the duration of travel from/to Port of Tanjung Emas.

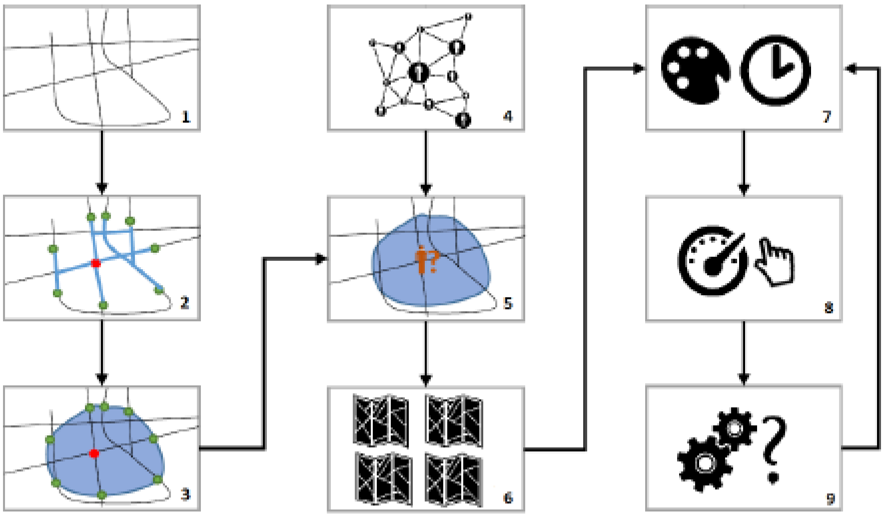

Figure 5-3 General Workflow for Creating an Isochrone Map

(Van Den Berg *et al.*, 2018)

5.3. Intermodal Transport Network Path Planning

As it is stated in the theoretical review chapter, some of IFT problems can be solved by using transshipment network model. Numerous research has been done by implementing transshipment model to IFT system, such as finding the optimum route and transport mode (Li *et al.*, 2023), IFT system with flexible schedules (Moccia *et al.*, 2011), and capacitated flow and production (Khurana, 2015). The variation of problem statement which can be solved by this model lies in the numerical formulation of this model, including the objective function and constraints. With the versatility of this model, the best result can only be achieved by a good translation of problem circumstances into numerical functions and values within the model.

The fundamental purpose of practicing IFT system in model-based analysis is to find the most efficient system before implementing it into reality. Therefore, a deep understanding of situations that could happen in a system shall be achieved in order to demonstrate the impact and result correctly. Van Duin and Ham (1998) suggests using cost model to breakdown the stakeholders and cost, while Januardi, Ramdhani and Harnaningrum (2020) use the same model of linear programming to consider the environmental cost of a distribution problem. The depth of its result really depends on what is the main objective of the research and how deep does the researcher do to provide the model's components.

In order to breakdown IFT system components, Rodrigue (2020) defines the four major functions of intermodal transport chain, including composition, connection (transfer), interchange, and decomposition. *Composition* (or first mile) is the process of packing freight, which ideally comes from various suppliers, into one single kind of larger package such as container. *Connection* (or transfer) is the term of moving consolidate packages by using larger mode such as ship or train. The connection part relies on economies of scale to create better efficiency. *Interchange* involves moving consolidated packages from one mode to another mode (regardless of mode type) to get continuous efficiency within the transport system. The most notable example of interchange is transshipment ports. *Decomposition* (or last mile) is the activity of fragmenting and transferring the consolidated freight to its distribution system. All processes within the IFT system are integrated because every activity is done by using the same kind of consolidated package such as container. This idea is important for the IFT system because all processes just include moving the consolidated package from one mode to another without handling each good inside that package. The illustration of IFT system components can be seen in Figure 5-4.

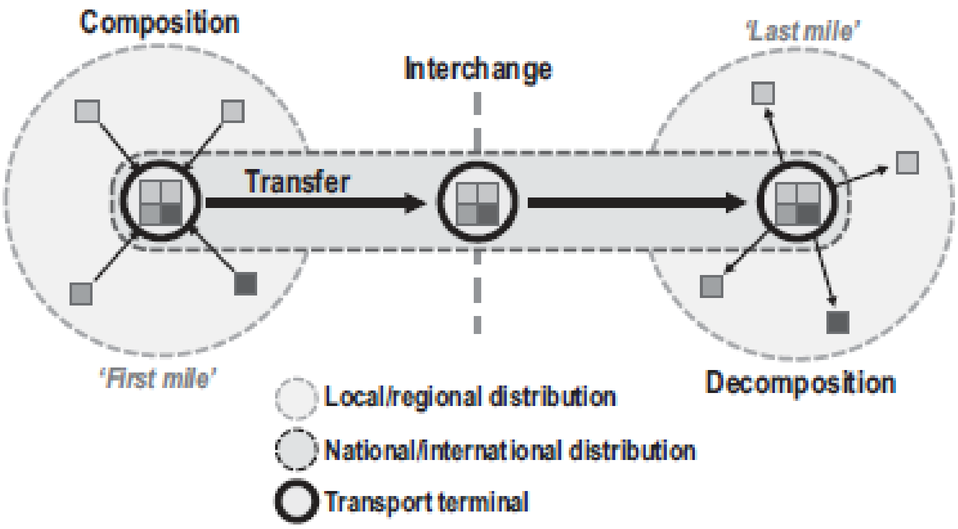

Figure 5-4 Illustration of The Intermodal Freight Transport System Components

(Source: Rodrigue, 2020)

Li *et al.* (2023) implements the idea of combining various kinds of mode and analyze the optimum route based on total cost for using combined route. They use the average transportation cost and average movement speed of transporting freight for each mode to calculate the total cost with any extra storage cost for each transshipment node. They provide some scenarios to compare the result of IFT systems which has a conclusion of the connection between cost and time, consisting variation in the certainty/uncertainty of demand and time. Hence, the mentioned research states that cost has inversed proportion to time. However, the combination of costs is usually different from one research project to another. In regards of that issue, Nariendra and Taufiq (2020) breaks the cost structure differently into movement cost and handling cost. The handling cost that is mentioned in that research is the cost to handle each package of freight (or container in that research) in the origin, destination, or transfer point. Therefore, the combination of cost to be analyzed in IFT system is different from one research to another depending on the objective of the research and the circumstances of implemented IFT system.

Chapter 6. Research Methodology and Data

It is essential to comprehend the guiding principles that guide the scientific inquiry process in order to produce relevant and trustworthy research results. This chapter explains the details of the current situation that is being reviewed in the research along with the planned scenarios and assumptions for each scenario, and research method and data which are being used to define the results in the next chapter. By outlining the methodological decisions and going into depth about the data collection procedures, this chapter tries to offer a firm basis for the study's validity and credibility. The travel time model will illustrate two kinds of situation, contours of travel time with unimodal and multimodal situation. For transport network model, there will be two other scenarios beside the current situation: multimodal scenario where all the freights are transported by using freight train and the combination of multimodal and unimodal transport networks where the decision to use either mode is based on the comparison of all alternative costs. Those three scenarios will be implemented in two kinds of situation: production situation where freights are delivered to PoTE from its hinterland and attraction situation where freights are delivered to PoTE hinterland from PoTE, make it a total of six scenarios. The method and data are based on two main models of this research: the travel time and network transportation models.

6.1. Model Description

A strong and subtle strategy is necessary to comprehend and forecast freight movement. This research uses mathematical and computational tools because they abstract complex real-world processes into a structured form, allow for examination, and reveal insights that might not be immediately obvious. The comparison between current and planned conditions can be explained in detail by using numbers as the result of a known model to solve the issue. The selection of an appropriate model is crucial since its assumptions and structure can have a significant impact on the research outcomes. This sub-chapter provides a comprehensive description of the travel time and network transportation models which are being used in this research as the main methodologies for examining the impact of railways in PoTE hinterland’s accessibility.

6.1.1. Travel Time Model

The travel time model’s aim is to estimate the travel duration from one point to other selected point(s) by using transportation network/system as geographical distance within those points.

In order to estimate the travel duration, the model also needs (average) velocity or movement speed of the vehicle itself. In addition, based on the calculated travel time throughout the researched area, the result will be illustrated by using contours with specific travel time for each contour. The simulation of this model is done by using *network analyst* tool in ArcMap 10.7 from ArcGIS. There are six steps to perform the travel time model:

- Step 1: configuring the network analyst environment.

  This step is a fundamental basis for a good result of the model by gathering or creating the data needed and configuring it to match the model needs. The type of data needed is shapefile (SHP) data for both the nodes and networks. The network needs to be imbued by length (can be generated by another tool in ArcMap) and velocity/movement speed information for each part of the network.
- Step 2: adding a network dataset to ArcMap.

  Before performing a network analysis, all data should be compiled inside a network dataset. A network dataset is a bundle of every feature or *shapefile* which will be used to perform the analysis. This step is mandatory for the model because the *network analyst* tool only performs the analysis from one specific network dataset.
- Step 3: creating the network analysis layer.

  A network analysis layer manages the inputs, properties, and results of a network analysis. For each sort of input as well as for the outcomes, it has an in-memory workspace with network analysis classes. Modeler can further specify the issue you are trying to solve by utilizing some of the network analysis layer's features. There are six types of network analysis layers: *route analysis, closest facility analysis, service area analysis, OD cost matrix analysis, vehicle routing problem analysis*, and *location-allocation analysis*. The service area analysis can be used to perform the travel time model.

  Network datasets are used exclusively for network analyses. As a result, a network data set must be coupled to a network analysis layer. If you create a network analysis layer using a geoprocessing tool, the network dataset will be set as a tool parameter.. A network dataset must be added to ArcMap before an analysis layer can be added.
- Step 4: adding network analysis objects.

  Features and data utilized as input and output during network analysis are referred to as network analysis objects. For example, the objects include *stops*, *barriers*, *routes*, and *facilities*. This step is required to put the data from *network dataset* to the model environment and describe the data as the model's control variables. This process can be done by manually inserting features into network analysis objects depending on each feature role in the model.

- Step 5: setting network analysis layer properties.

  Compared to its network analysis objects, the network analysis layer contains attributes that are more analysis-specific. The network impedance characteristic to employ, the limitation attributes to abide by, and so forth are examples of general analytic features. There are further characteristics specific to the type of analysis being done. These properties are accessible through the Layer Properties dialog box of an analysis layer.
- Step 6: performing the analysis and displaying the result.

  Once all the steps have been completed, the model is ready to perform. The output will be contours of travel duration as it is described in the network analysis layer properties.

The model calculates the travel duration by projecting the distance of two points with a specific network system and datum, and then converts the distance to duration mathematically by using the velocity input. Each network system can be simple or complex, depending on the data, and every part of the network system can have specific characteristics such as velocity and cost. After calculating the travel duration, the model generalizes the result by creating contours of travel time. The result will be better if the network system data is comprehensive, otherwise, the contours will be shaped "unnatural" due to the absence of data needed.

6.1.2. Network Transportation Model

A network transport model is a mathematical depiction of the transportation network that includes both the network's structural and functional elements. In order to assess, forecast, and optimize the flow of commodities, services, or people, the system is divided into nodes, or points of interest, and links, or routes linking these nodes. There are three components needed for performing this model: nodes, links, and flows. Each component can have its own characteristic and attribute, which illustrate the real situation of the network as close as possible. This research focuses on solving the specific kind of network transportation model, the transshipment problem.

The transshipment problem can solve the network transportation problem with intermediary node within the model environment. Therefore, transshipment model can explain the optimum choice of intermediary node beside the optimum cost (or objective value). The detail explanation of how this model solve the problem has described in sub-chapter 3.3. This research uses two tools for modeling this problem: by using OMPR::GLPK (R 4.3.1) as main model and OpenSolver (Microsoft Excel) to verify the result, as both methods use Mixed Integer Linear Programming (MILP) to solve the problem. The flowchart of typical main solving loop of MILP can be seen in

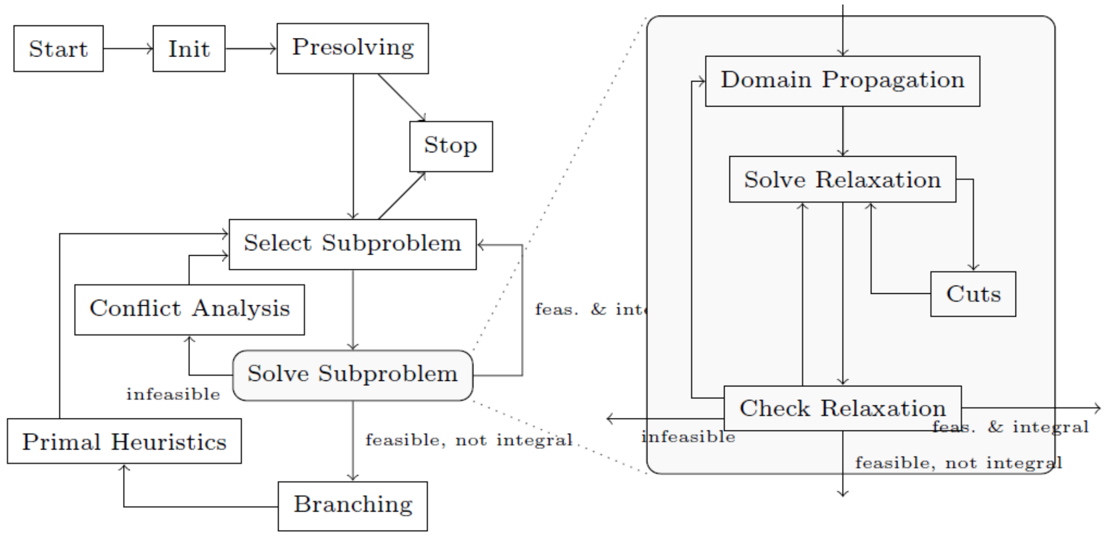

Figure 6-1 Flowchart of Mixed Integer Linear Programming Solver

(Ralphs *et al.*, 2018)

Generally, both tools use the same dataset to model this problem. This dataset includes supply and demand volumes, origin, destination, intermediary node, and flow cost. The model will generate optimum cost which is the summation of transportation cost for transporting specific volume of freight in every OD node within the model environment. The optimum intermediary node can be decided by taking a look at the throughput of intermediary node as the result of this model. Therefore, this model can predict how efficient the planned network is in terms of cost and deciding intermediary node location.

6.2. Description of Current Situation and Scenarios

6.2.1. Current Situation in PoTE Hinterland

The Port of Tanjung Emas is the biggest port in Central Java Province which has a hinterland of two provinces: Central Java and Special Region of Yogyakarta Province. In current situation, almost all of the freights that come across PoTE from/to its hinterland are carried by truck and produces a huge traffic load within a wide radius from the port (Napitupulu, Jinca and Riyanto, 2022). In general, the OD pair for all the freights in PoTE hinterland are divided into each municipality as the demand from each municipality has some relations to its demographic statistic (Ministry of Transportation, 2022). The majority of demand comes from areas closer to PoTE and it is predicted to be spiking in the near future as the development of two big industrial parks (Batang and Cilacap Industrial Park) is already on going. This situation creates more urgency of alternative solution to the traffic condition.

Within its hinterland, PoTE has 40 municipalities scatted across two provinces, and each municipality has their own characteristic of urgency to use PoTE as their main facility to transport its freight, as the PoTE hinterland itself has several ports nearby. With that particular reason, the total freight of each municipality will be generated by using PoTE yearly throughput instead of a whole freight production of every municipality (the calculation will be explained later in this chapter). The Port of Tanjung Emas and its hinterland OD points are depicted in Figure 6-2.

6.2.2. Scenarios for Travel Time and Transport Models

The Port of Tanjung Emas has a huge dependency of road transport to its hinterland in current situation and it creates a huge traffic load along the road from/to the port. The main purpose of this research is to analyze the impact of railways for PoTE connectivity to its hinterland and then use the transport cost to compare the current situation and planned situation where railways function as an alternative haulage to road transport. The geographic scope of all models and scenarios in this research is within PoTE hinterland, which is Central Java and Special Region of Yogyakarta Provinces, as we create a closed environment of that geographic scope for both models to make the calculation less complicated.

Travel time model will illustrate the time needed to transport the freight from/to PoTE and then divide it into ranges of travel time which ultimately displayed as a map of contours. There will be two scenarios for this model: the current situation and the planned situation. The current situation simulates the travel time of freight while using truck as its transport mode. On the other hand, the planned situation simulates the travel time of freight while using railways as its main haulage and truck for transportation to/from transfer point. In the planned situation, transfer points have direct access to PoTE with higher transport speed than using the road, as it is proven from various literature (the detail of average movement speed of each mode will be explained later in this chapter). Brief description for all travel time model scenarios in this research can be seen in Table 6-1.

Table 6-1 Short Description about Travel Time Model Scenarios

Scenario	Short Description
Current Situation	Unimodal situation (road haulage)
Planned Situation	Multimodal situation (railways as the main haulage)

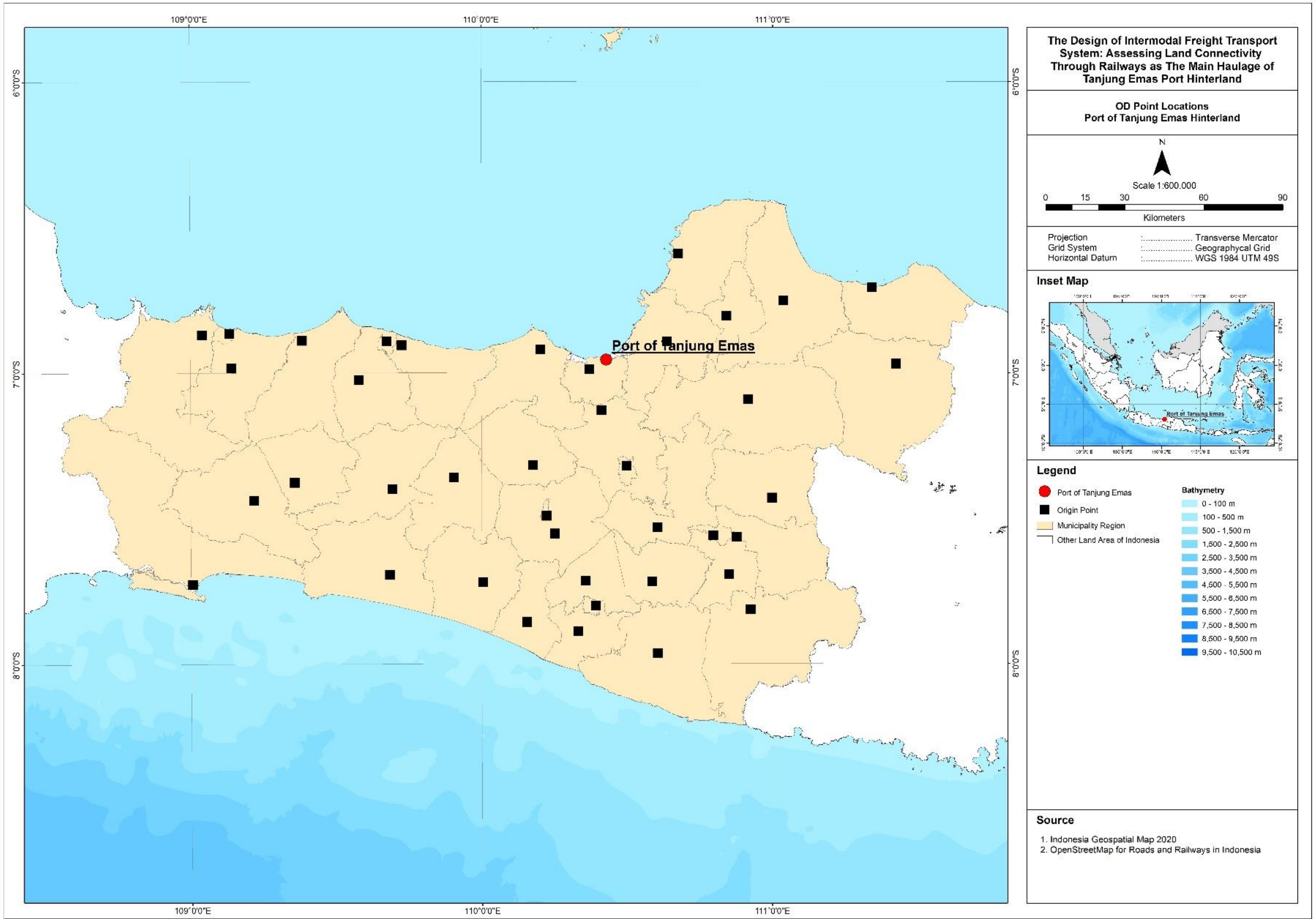

Figure 6-2 OD Point Locations for Port of Tanjung Emas Hinterland

The transport model will exemplify the transport cost for each scenario and preferable transfer point(s) for planning a multimodal transport system. In this model, each scenario will be treated as a *transshipment problem* – every scenario is based on three kinds of node: origin, intermediary, and destination. For truck/road haulage in unimodal case, intermediary node is a dummy node – a middle point for every line which has no handling cost. The dummy node is compulsory for that specific case to make all scenarios treated uniformly with the same kind of model. In the first scenario, the road acts as the main and only haulage for PoTE hinterland(unimodal). To simplify the situation of this scenario, each OD uses distance and total demand as their dependent variables and transportation cost (per km) and handling cost as the independent variables to calculate the total transport cost. As for handling cost, there will be 3 types of handling cost: one for each node except for dummy node. There will be no time dependent variable in this research due to limited information regarding that matter. Hence, the calculation will be a pure transport cost between origin and destination.

For the second scenario, the model processes railways as main haulage to transport between origin and destination and uses road to transport freight from municipalities to transfer points (vice versa). The third scenario uses both unimodal and multimodal as alternatives haulage for freight transport and chooses the best mode to transport the freight by the lowest cost combination available. Those three scenarios are implemented in two situations: production and attraction conditions which occur when the freight is transported to and from PoTE, respectively. The brief description for all scenarios can be seen in Table 6-2 and the details of assumption for all those scenarios will be explained in the sub-chapter below.

Table 6-2 Short Description about Network Transport Model Scenarios

Scenario	Short Description
Scenario 1	Unimodal (truck) – PoTE as ultimate destination
Scenario 2	Input railways as main haulage – PoTE as ultimate destination
Scenario 3	Combination of scenario 1 and 2 – PoTE as ultimate destination
Scenario 4	Unimodal (truck) – Municipalities as ultimate destinations
Scenario 5	Input railways as main haulage – Municipalities as ultimate destinations
Scenario 6	Combination of scenario 4 and 5 – Municipalities as ultimate destinations

6.3. Data and Assumption for Travel Time Model

Travel time model requires 4 main components for modelling purpose: origin point, destination point, transportation network, and average velocity for each part of network. The model itself will navigate the best route for assigned OD depending on specific variable such as length, duration, and cost. In this model, two scenarios are modelled based on kind of mode to travel: unimodal and multimodal. Assumptions and boundaries for all scenarios in this research are divided into two issues: actors and service. The sections below will explain these matters in detail.

6.3.1. Data and Assumption for Actors

For all scenarios, the concept of travel time model pretty straight forward, to illustrate the time needed to travel from origin to destination by using the transport network. There are 40 points of origin and one destination in both scenarios, with the origins are municipalities within PoTE hinterland and the destination is PoTE itself. In unimodal scenario, the route shall be decided by looking at the shortest duration of travel from destination to origin. Furthermore, the complexity of multimodal transport for travel time shall be determined by looking at the combination of travel time from origin to transfer point and from transfer point to destination. The transfer points are decided by looking at the available existing railway station in PoTE hinterland. The impact of railways as alternative haulage between OD points shall be displayed as in the change of travel time needed to transport the freight by looking at the result of this travel time model. The detail of which actor served in every scenario in travel time model can be seen in Table 6-3.

Table 6-3 OD Actors for All Scenarios for Travel Time Model

Scenario	Assumption and Boundary
Current Situation	40 origins and 1 destination
Planned Situation	40 origins, 26 transfer points, and 1 destination

6.3.2. Data and Assumption for Services

As it is stated before, the geographic scope of travel time model for this research is a combination of administrative border of two provinces: Central Java and Special Region of Yogyakarta Provinces. Hence, the network for transporting freight also uses the available network within the geographical boundary. There are three main components of services to set-up the travel time model: origin, destination, and network, and the mentioned network is divided into another three components in this research: road, transfer point, and railway, and are gathered from Badan Informasi Geospasial (Indonesia Geospatial Information Agency) and OpenStreetMap (online geographic database). The service components for travel time model can be seen in Figure 6-3.

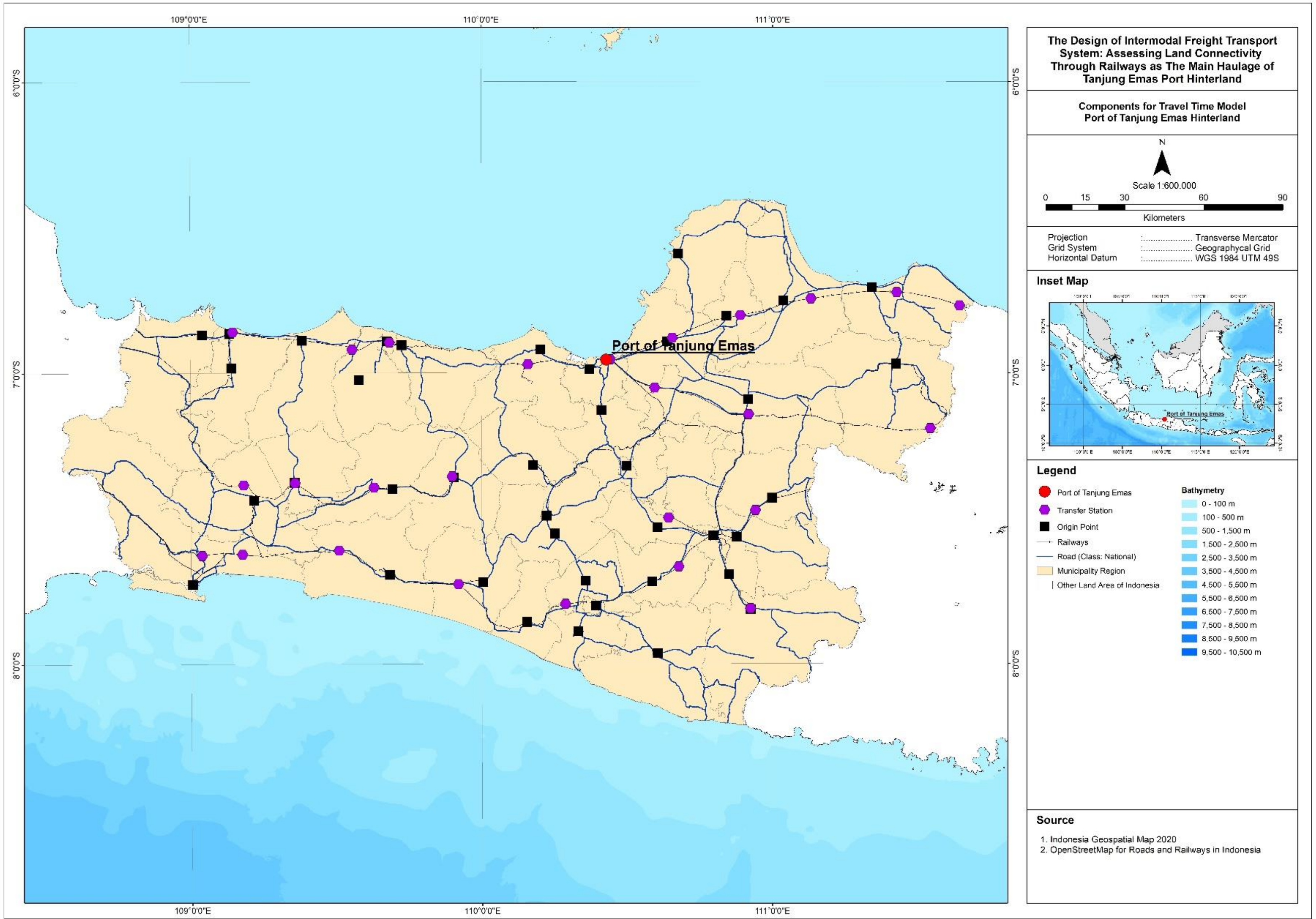

Figure 6-3 Components for Travel Time Model

In this research, the travel time model does not compile any traffic load and handling time, so it is assumed that the freight transporting time is a total movement time of its mode without any distraction. The velocity of road and railway are adjusted accordingly by reference to available research. Based on the previous research, the average freight truck velocity in Central Java Province is 26.7 km/hour (Napitupulu, Jinca and Riyanto, 2022). However, this research uses 30 km/hour instead of 26.7 km/hour in average truck velocity because the slower average truck velocity is for congestion condition. On the other hand, average freight train velocity is 50 km/hour (Sharma & Associates, 2013; Purwati, 2021). Those numbers will provide ample components to predict the travel time for each mode within the hinterland's network.

6.4. Data and Assumption Transport Network Model

Every research project functions within a framework of particular presumptions. When it comes to research, assumptions are circumstances or facts that are assumed to be true even in the absence of empirical data. The main presumptions that have guided this research are outlined in this section, while the main equation for this model already explained in sub-chapter 3.3.2. When it comes to research, assumptions are circumstances or facts that are assumed to be true even in the absence of empirical data. They are vital to the research process's foundation, but it is also critical to articulate. Assumptions and boundaries for all scenarios in this research are divided into four issues: actors, service, time, and cost. The sections below will explain these matters in detail.

6.4.1. Data and Assumption for Actors

For all scenarios, it is assumed that the provider of freight transport between PoTE and its hinterland is a single provider so that this single entity can plan all transport needed for the demand and supply then modify the network system to fulfill the needs of transport efficiently. There will be several OD actors that are included in this research, the detail of which actor served in every scenario can be seen in Table 6-4.

Table 6-4 OD Actors for All Scenarios for Transport Network Model

Scenario	Assumption and Boundary
Scenario 1	40 origins, 40 intermediaries (dummies), and 1 destination
Scenario 2	40 origins, 26 intermediaries (transfer points), and 1 destination
Scenario 3	40 origins, 66 intermediaries (dummies and transfer points), and 1 destination
Scenario 4	1 origin, 40 intermediaries (dummies), and 40 destinations
Scenario 5	1 origin, 26 intermediaries (transfer points), and 40 destinations

Scenario	Assumption and Boundary
Scenario 6	1 origin, 66 intermediaries (dummies and transfer points), and 40 destinations

6.4.2. Data and Assumption for Services

The total throughput of PoTE in 2021 is around 850 thousand TEUs and this is the base data for calculating supply-demand in each OD point. A research (Ministry of Transportation, 2022) separates the throughput of PoTE into 'production' and 'attraction' for municipalities within its hinterland. Production stands for the amount of freight that each municipality produces, and attraction represents the total amount of freight that PoTE sends to every municipality. This information is processed to be supply-demand values as the model will calculate the optimum network equilibrium by using transport problem method (see Sub-Chapter 3.3). The linear function of municipality throughput is described in equations below.

$$P_i = 0.19\,.X_1 - 0.51\,.X_2 \qquad R^2 = 0.86 \qquad (3)$$

$$A_i = 1.03\,.X_1 + 13.78\,.X_2 \qquad R^2 = 0.85 \qquad (4)$$

Note:

P_i = container production for each municipality (TEU/year)

A_i = container attraction for each municipality (TEU/year)

X_1 = municipality population (people)

X_2 = gross regional domestic product (billion Rupiah)

The details of population and gross regional domestic product which are being used for calculating the freight volumes and the result of freight volumes for every municipality in production and attraction situations can be seen in Table 6-5 and Table 6-6 respectively.

Table 6-5 Population and Gross Regional Domestic Product of Every Municipality in PoTE Hinterland in 2021

No	Origin	Population (people)	Gross Regional Domestic Product (billion Rupiah)
1	Kota Tegal	275,781	11,290.27
2	Brebes	1,992,685	33,456.33
3	Pemalang	1,484,209	18,916.26
4	Kota Pekalongan	308,310	16,615.07
5	Batang	807,005	15,764.27
6	Kendal	1,025,020	31,632.28
7	Kota Semarang	1,656,564	144,710.66
8	Demak	1,212,377	18,856.42

No	Origin	Population (people)	Gross Regional Domestic Product (billion Rupiah)
9	Kudus	852,443	69,556.93
10	Pati	1,330,983	31,559.08
11	Jepara	1,188,510	21,944.23
12	Rembang	647,766	13,925.52
13	Blora	886,147	18,126.45
14	Purwodadi	1,460,873	20,115.53
15	Sragen	983,641	27,355.15
16	Surakarta	522,728	36,211.25
17	Karanganyar	938,808	27,034.11
18	Wonogiri	1,049,292	21,251.00
19	Sukoharjo	911,603	27,634.12
20	Klaten	1,267,272	28,531.11
21	Boyolali	1,070,247	23,447.37
22	Salatiga	193,525	9,820.29
23	Kab. Semarang	1,059,844	35,946.10
24	Kota Magelang	121,610	6,513.89
25	Temanggung	794,403	15,387.93
26	Wonosobo	886,613	14,064.76
27	Banjarnegara	1,026,866	15,536.48
28	Purbalingga	1,007,794	17,731.44
29	Purwokerto	1,789,630	40,686.81
30	Purworejo	773,588	13,582.56
31	Kebumen	1,361,913	20,253.06
32	Cilacap	1,963,824	91,944.59
33	Magelang	1,305,512	23,661.71
34	Kab. Pekalongan	976,504	16,615.07
35	Kab. Tegal	1,608,611	25,402.91
36	Bantul	998,647	19,773.33
37	Gunungkidul	758,168	14,216.36
38	Kuloprogo	443,283	8,778.80
39	Sleman	1,136,474	35,786.98
40	Kota Yogyakarta	376,324	28,390.08

(Central Bureau of Statistics, 2022)

Table 6-6 Freight Volume from and to Port of Tanjung Emas

No	Origin	Production (Box)		Attraction (Box)	
		20 Feet	40 Feet	20 Feet	40 Feet
1	Kota Tegal	1,215	912	1,095	821
2	Brebes	9,416	7,062	7,594	5,695
3	Pemalang	7,094	5,320	5,617	4,213
4	Kota Pekalongan	1,305	979	1,250	938
5	Batang	3,784	2,838	3,090	2,318
6	Kendal	4,652	3,489	4,001	3,001

No	Origin	Production (Box)		Attraction (Box)	
		20 Feet	40 Feet	20 Feet	40 Feet
7	Kota Semarang	6,276	4,707	7,076	5,307
8	Demak	5,749	4,312	4,611	3,458
9	Kudus	3,295	2,471	3,610	2,707
10	Pati	6,167	4,626	5,132	3,849
11	Jepara	5,590	4,193	4,542	3,407
12	Rembang	3,021	2,266	2,489	1,867
13	Blora	4,145	3,109	3,398	2,549
14	Purwodadi	6,962	5,222	5,538	4,154
15	Sragen	4,504	3,378	3,820	2,865
16	Surakarta	2,106	1,580	2,172	1,629
17	Karanganyar	4,287	3,215	3,651	2,739
18	Wonogiri	4,910	3,683	4,023	3,017
19	Sukoharjo	4,144	3,108	3,555	2,666
20	Klaten	5,892	4,419	4,877	3,658
21	Boyolali	4,985	3,739	4,115	3,086
22	Salatiga	828	621	781	586
23	Kab. Semarang	4,767	3,576	4,158	3,118
24	Kota Magelang	516	387	493	370
25	Temanggung	3,727	2,795	3,041	2,281
26	Wonosobo	4,201	3,151	3,374	2,530
27	Banjarnegara	4,875	3,657	3,902	2,927
28	Purbalingga	4,752	3,564	3,846	2,885
29	Purwokerto	8,316	6,237	6,889	5,167
30	Purworejo	3,648	2,736	2,952	2,214
31	Kebumen	6,471	4,853	5,173	3,880
32	Cilacap	8,497	6,373	7,869	5,902
33	Magelang	6,146	4,610	4,987	3,740
34	Kab. Pekalongan	4,612	3,459	3,723	2,792
35	Kab. Tegal	7,623	5,717	6,120	4,590
36	Bantul	4,679	3,510	3,826	2,869
37	Gunungkidul	3,563	2,673	2,899	2,175
38	Kuloprogo	2,077	1,558	1,698	1,274
39	Sleman	5,149	3,862	4,440	3,330
40	Kota Yogyakarta	1,486	1,114	1,579	1,184

6.4.3. Data and Assumption for Time Issues

This research focuses on the benefit of implementing railways as alternative haulage for PoTE hinterland, so it will not specifically address the technical issue of transporting freight but comparing the current condition with the planned condition. For that reason, this research calculates the spread of freight in the designed network system within an entire year, not on a daily or monthly basis. Sub-chapter 6.4.2 already explained the freight volume from and to PoTE as this research uses 2021 data of PoTE throughput. Technical time issues such as handling time, transit time, or terminal operating hours are not being considered in this research. Hence, the closest time related variable in this research is yearly throughput of PoTE.

6.4.4. Data and Assumption for Cost Issues

All scenarios use the same assumptions of cost issues, and it is divided by types of mode and freight. All cost issues are calculated according to the research of (Nariendra and Taufiq, 2020) which calculated the cost of transporting freight from Bandung to Port of Tanjung Priok. The mentioned reference is considered to be the core of cost calculation because the research geographic location is relatively close to this research geographic location. The cost components which are utilized in the transport cost are movement cost (Rupiah/km) and handling cost (Rupiah/box). The details of transport costs are described in the table below.

Table 6-7 Transport Costs Breakdown for Truck and Train

No	Cost Variable	Mode	
		Truck	Train
1	Movement cost (Rupiah/km)	8,108.00	3,680.22
2	Municipality handling cost (rupiah/box) - 20 feet container - 40 feet container	 200,000 300,000	
3	Transfer point handling cost (rupiah/box) - 20 feet container - 40 feet container	 - -	 91,000 151,000
4	PoTE handling cost (rupiah/box) - 20 feet container - 40 feet container	 1,630,000 2,160,000	

Chapter 7. Results

The purpose of this chapter is to present the findings derived from the data analysis conducted in this study. The analysis was designed to explore the impact of railways for freight transport in Port of Tanjung Emas hinterland. The results are presented in a systematic and detailed manner, aligning with the research objectives outlined in Chapter 1. The chapter is structured as follows: the first section provides the result of travel time model for both existing and planned conditions. The subsequent sections then delve into the detailed findings for existing and planned conditions as comparisons of total transport and handling costs between both conditions.

7.1. Travel Time Model

This research use two different scenarios to assess the impact of intermodal freight transport system in PoTE hinterland: 1) unimodal travel time model: the existing condition which road transport dominates all freight transport activities, and 2) intermodal travel time model: the planned condition which every gravity points will use IFT system to transport the freight. The results of those models are displayed as contours maps of travel time within the PoTE hinterland. To summarize the basic input and method for the model, the assumptions that this research use to generate the travel time model are:

1. The average truck movement speed is 30 km/h.
2. The average freight train movement speed is 50 km/h.
3. Shortest route possible for every point.
4. Road and Railway transport without any disturbance or interruption (such as traffic light and congestion) within the voyage.
5. Transfer points without considering handling and waiting time.

Based on the travel time model, the scope of travel time radius from Port of Tanjung Emas to Its hinterland (vice versa) is mostly within 8 hours. This result can illustrate the existing condition of Port of Tanjung Emas connectivity to its hinterland, which is dominated by truck (unimodal) as their main mode. The distances from every point in the hinterland are calculated by using the shortest route possible, so this map technically illustrates the contours of minimum time for traveling to/from Port of Tanjung Emas. The result of travel time model for existing condition of Tanjung Emas Port and its hinterland can be seen in Figure 7-1. Based on the travel time model, most areas can travel in 4-6 hours to/from PoTE by truck, representing 35.45% of

PoTE hinterland. The shortest (0-2 hours of travel) and longest (more than 8 hours of travel) duration are the two least areas of travel time contours, which are 8.53% and 8.30% respectively.

On the other hand, the intermodal travel time model shows that the overall travel time will be reduced by implementing that system as the lesser travel-time contours are huger than the unimodal model. The 0-2 hours travel time contour area increases to 15.29% and the longest travel time contour area (more than 8 hours) decreases to 1.05% of PoTE hinterland area. Within 6 hours of travel time, the network system can accommodate more than 87% of PoTE hinterland area. This result suggests that by using intermodal transport network, PoTE hinterland will have a better coverage of travel duration. Although this result indicates an incredibly positive result, the operation of IFT system needs to consider the handling time for each cargo and freight train schedule in order to maximize the benefit of IFT system. The result of multimodal travel time model for Tanjung Emas Port's connectivity to its hinterland can be seen in Figure 7-2 and the overlay of both kinds of mode as comparison to each travel time contour can be seen in Figure 7-3. The comparison of coverage area for each travel time classification and kinds of mode can be seen in Table 7-1.

Table 7-1 The Comparison of Travel Time Between Unimodal and Intermodal Transport System within Port of Tanjung Emas Hinterland

Travel Time (hours)	**Area within PoTE Hinterland (%)**	
	Unimodal	**Intermodal**
0-2	8.53%	15.29%
2-4	29.99%	42.93%
4-6	35.45%	29.63%
6-8	17.74%	11.09%
>8	8.30%	1.05%

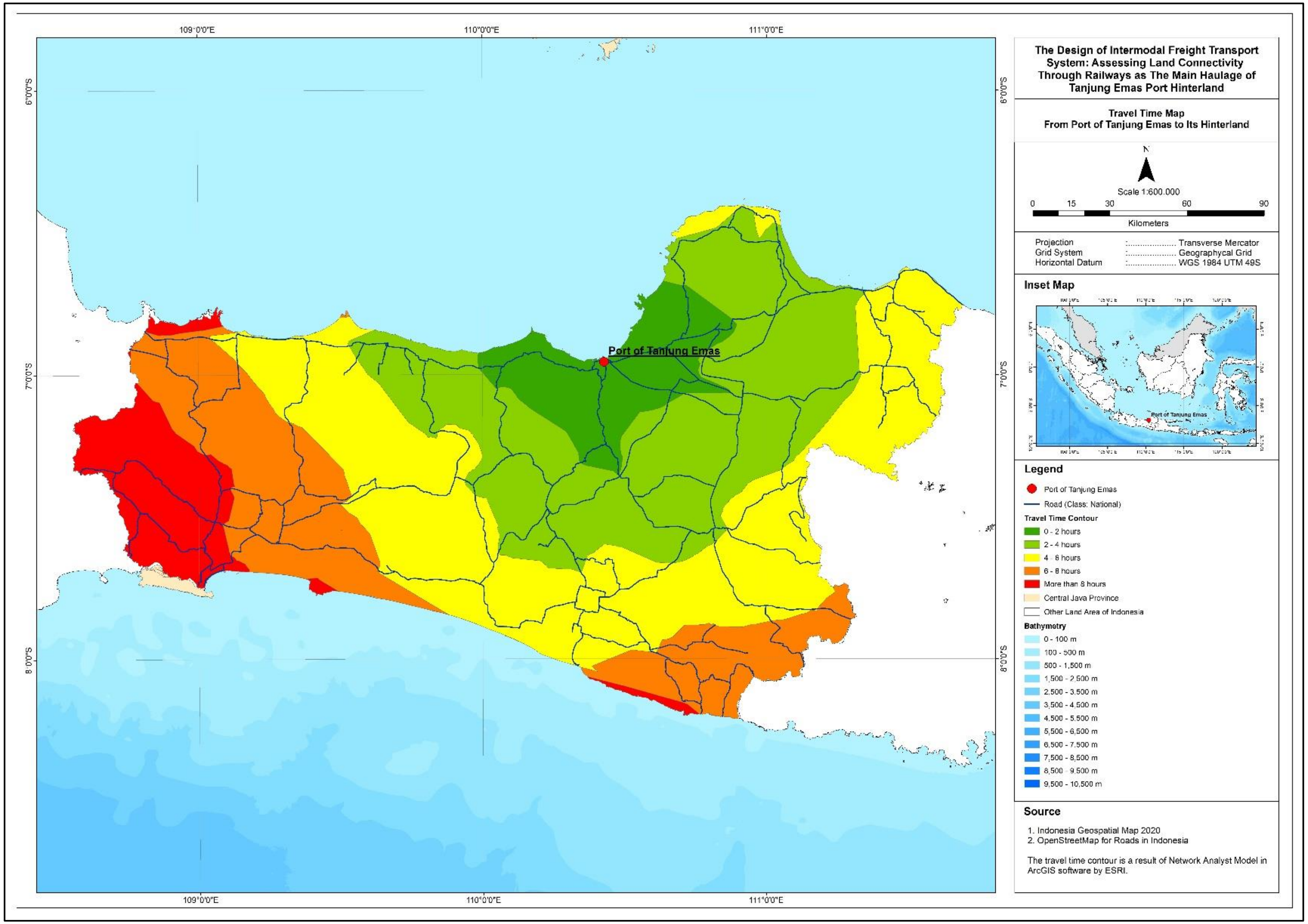

Figure 7-1 The Illustration of Unimodal Travel Time Model from Port of Tanjung Emas to Its Hinterland

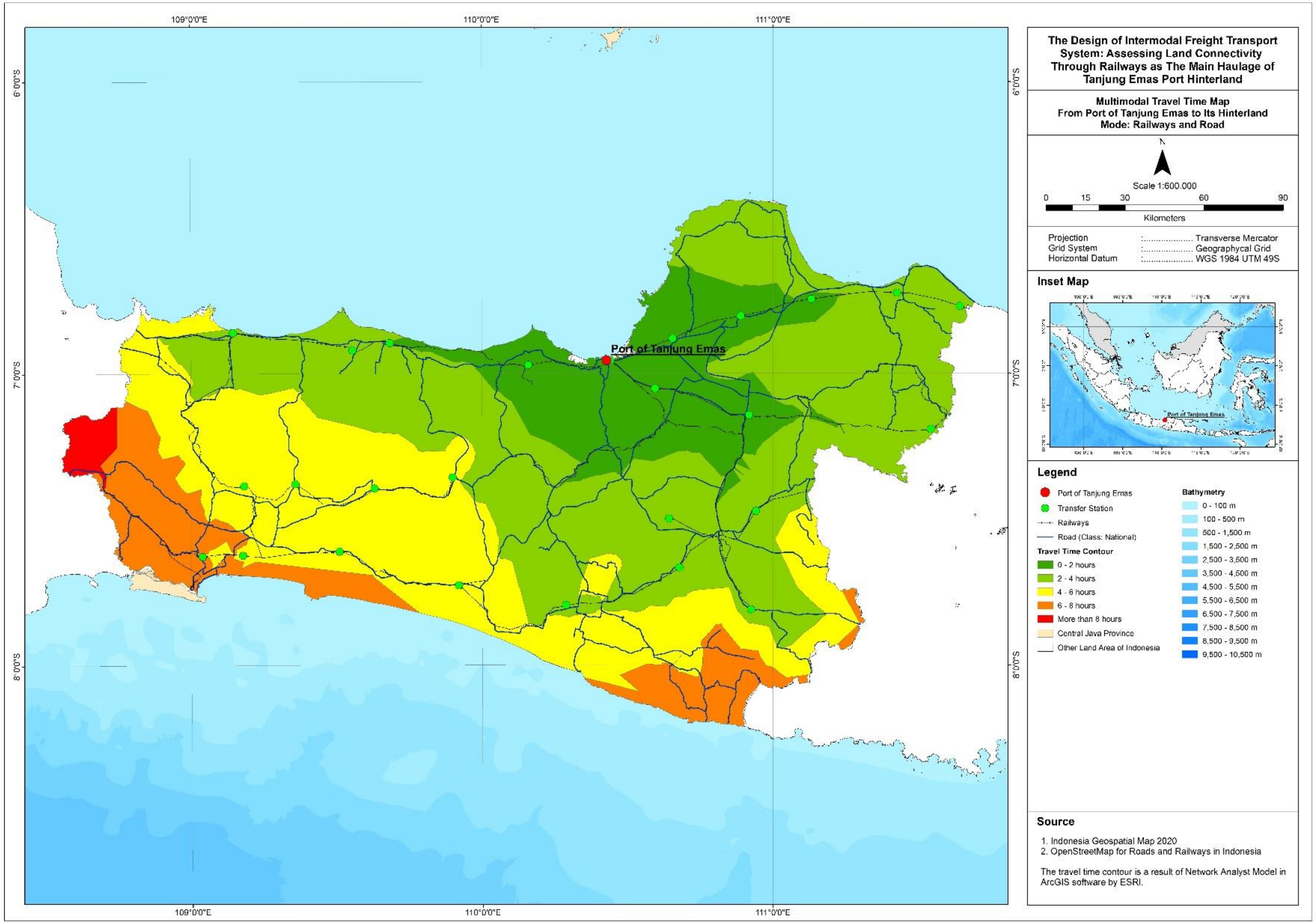

Figure 7-2 The Illustration of Multimodal Travel Time Model from Port of Tanjung Emas to Its Hinterland

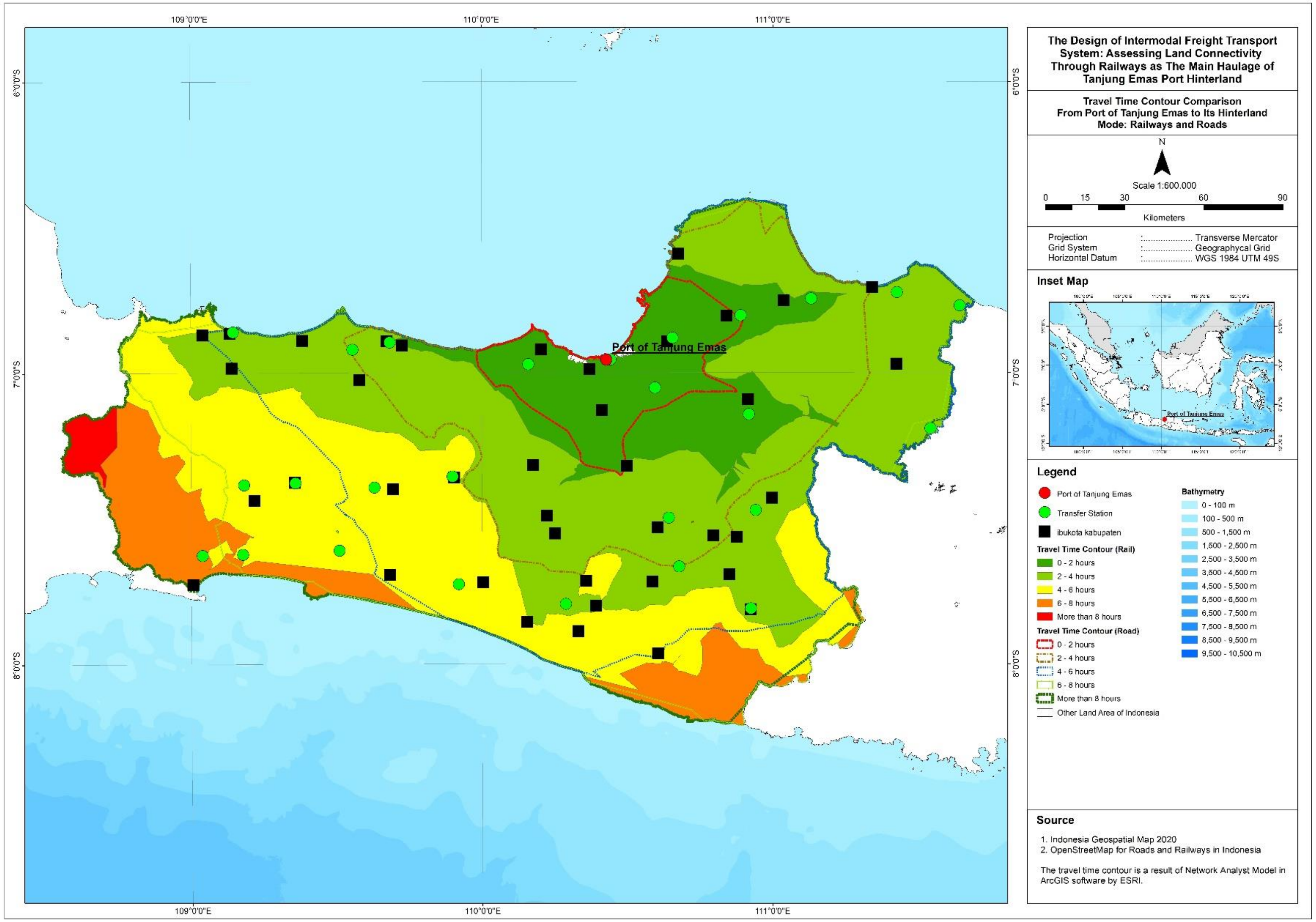

Figure 7-3 The Overlay Result of Unimodal and Multimodal Travel Time Contour

7.2. Transport Model Comparisons

Comparisons of the transport model between two conditions (existing and planned conditions) are being made by juxtaposing the total transport and handling costs for each scenario. Each scenario is treated as a transshipment problem (a specific transport problem with an intermediary node between origin and destination) and calculated by using mixed-integer programming (MIP). The calculation also differentiates between 20F and 40F container types. There are several scenarios that are being implemented in this research:

1. The main haulage is truck/road, consisting of 40 origins, 40 dummy intermediaries and 1 destination.
2. The main haulage is freight train/railways, consisting of 40 origins, 26 transfer points/intermediaries, and 1 destination; and
3. The combination between both haulages, which can be chosen based on the minimum transportation cost to the destination, consist of 40 origins, 66 intermediaries, and 1 destination.

7.2.1. Hinterland Freight Production's Transport Model

In order to verify the result, the comparisons for transport model between each condition would be assessed by using two main softwares (engine), *Microsoft Excel* (OpenSolver) and *R* (OMPR::GLPK). Both engines serve the same purpose in this research: to analyze the optimum cost/solution for transporting the goods by calculating the linear solution for every set of product-origin-intermediary-destination which has a specific cost to serve the whole supply and demand and then combines all sets to create the ideal solution in term of cost. The optimum solution for every scenario that are being discussed can be seen in Table 7-2.

Table 7-2 Optimum Solution Comparison for Every Scenario in Production Situation

Scenario	Objective Value (in million rupiah)
Scenario 1	1,004,372
Scenario 2	922,031
Scenario 3	917,182

From the optimum solutions for each scenario, as appeared in Table 7-2, the yearly total cost of freight transport to the Port of Tanjung Emas is reduced by 8.20%–8.68% if the railways are being used as the main or alternative haulage. Scenario 2 creates a decrease in total transport cost of around 8.20%, mainly because the cost per km of transport by using railways is far cheaper than using roads for most of the origins. Although multimodal transport creates an additional expense because of the transfer point's handling, it is still considered acceptable due to the far cheaper cost per km of railway transport. Scenario 3 also creates a decrease in total transport costs of around 8.68% from the existing condition. Some origins still get a better cost for full truck transport rather than using railways as their main haulage (mostly because of their location, which is relatively close to the Port of Tanjung Emas). In the real world, it also creates competitiveness for railway transport so that they cannot push the cost too high. In general, of all origins that are being considered in the calculation, they tend to use railways as their main haulage in order to minimize the cost. Projected throughput of each transfer point for both scenarios can be seen in Table 7-3.

Table 7-3 Predicted Freight Throughputs between Scenarios for Every Transfer Point in Production Situation

Transfer Point Location	**20F Yearly Throughput (box)**		**40F Yearly Throughput (box)**	
	Scenario 2	**Scenario 3**	**Scenario 2**	**Scenario 3**
Location 1	18,254	18,254	13,691	13,691
Location 2	7,094	7,094	5,320	5,320
Location 3	9,701	9,701	7,276	7,276
Location 4	17,455	9,076	13,092	6,808
Location 5	17,705	0	13,280	0
Location 6	14,634	8,885	10,976	0
Location 7	6,167	6,167	4,626	4,626
Location 8	3,021	3,021	2,266	2,266
Location 9	4,145	4,145	3,109	3,109
Location 10	0	0	0	0
Location 11	0	0	0	0
Location 12	6,962	6,962	5,222	5,222
Location 13	828	0	621	0
Location 14	8,791	8,791	6,593	6,593
Location 15	9,054	9,054	6,791	6,791
Location 16	10,941	10,941	8,206	8,206
Location 17	11,905	11,905	8,930	8,930
Location 18	10,119	10,119	7,589	4,853
Location 19	0	0	0	0
Location 20	0	0	0	0
Location 21	8,497	8,497	6,373	6,373
Location 22	7,091	7,091	5,319	5,319
Location 23	8,316	8,316	6,237	6,237
Location 24	4,752	4,752	3,564	3,564
Location 25	0	0	0	0
Location 26	0	0	0	0

As it can be seen in Table 7-3, not all transfer points are optimum location for freight transport to Port of Tanjung Emas. From twenty-six locations of transfer point, six of them are not considered as good locations for transfer point location because of the cost to transport from those locations are higher than using the unimodal (by truck) or multimodal method to the other transfer points. The conventional method of using truck also has some bargain in a few origins due to its source close to Port of Tanjung Emas or simply because the cost of using multimodal method from that origin location is just cost higher than using unimodal method. The optimum location for transfer points that spread across Port of Tanjung Emas hinterland based on the optimum solution in the model can be seen in Figure 7-4 and the preference of each gravity point for transport network system in production situation can be seen in Table 7-4.

Table 7-4 Preference of Transport Network System for Each Gravity Points in Production Situation

Gravity Point	Preferred Network System			Gravity Point	Preferred Network System	
	20F	40F			20F	40F
Kota Tegal	IFT	IFT		Boyolali	IFT	IFT
Brebes	IFT	IFT		Salatiga	Truck	Truck
Pemalang	IFT	IFT		Kab. Semarang	Truck	Truck
Kota Pekalongan	IFT	IFT		Kota Magelang	Truck	Truck
Batang	IFT	IFT		Temanggung	Truck	Truck
Kendal	Truck	Truck		Wonosobo	IFT	IFT
Kota Semarang	Truck	Truck		Banjarnegara	IFT	IFT
Demak	Truck	Truck		Purbalingga	IFT	IFT
Kudus	IFT	Truck		Purwokerto	IFT	IFT
Pati	IFT	IFT		Purworejo	IFT	Truck
Jepara	IFT	Truck		Kebumen	IFT	IFT
Rembang	IFT	IFT		Cilacap	IFT	IFT
Blora	IFT	IFT		Magelang	Truck	Truck
Purwodadi	IFT	IFT		Kab. Pekalongan	IFT	IFT
Sragen	IFT	IFT		Kab. Tegal	IFT	IFT
Surakarta	IFT	IFT		Bantul	IFT	IFT
Karanganyar	IFT	IFT		Gunungkidul	IFT	IFT
Wonogiri	IFT	IFT		Kuloprogo	IFT	IFT
Sukoharjo	IFT	IFT		Sleman	IFT	IFT
Klaten	IFT	IFT		Kota Yogyakarta	IFT	IFT

7.2.2. Hinterland Freight Attraction's Transport Model

The method to produce transport model for this situation is technically the same as in production transport model, with differences in list of origin and destination and the supply-demand values. The major difference of this case to previous case is the origin node of this case is PoTE rather than the municipalities as in production case. The optimum solution for every scenario in this situation can be seen in Table 7-5.

Table 7-5 Optimum Solution Comparison for Every Scenario in Attraction Situation

Scenario	Objective Value (in million rupiah)
Scenario 4	847,258
Scenario 5	779,020
Scenario 6	774,314

The pattern of optimum solution in attraction situation is the same as in production situation – scenario 4 (unimodal) has the highest total transportation cost than the others and scenario 6 (combination between unimodal and multimodal) is the lowest cost of them all. Scenario 5 creates a decrease in total transport costs of around 8.05%, mainly because the cost per km of transport by using railways is far cheaper than using roads for most of the origins. Scenario 3 also creates a decrease in total transport costs by around 8.61% from the existing condition. Some origins still get a better cost for full truck transport rather than using railways as their main haulage (mostly because of their location, which is relatively close to the Port of Tanjung Emas). In general, of all origins that are considered in the calculation, they tend to use railways as their main haulage in order to minimize the cost, same as production situation. Projected throughput of each transfer point for both scenarios can be seen in Table 7-6.

Table 7-6 Predicted Freight Throughputs between Scenarios for Every Transfer Point in Attraction Situation

Transfer Point Location	20F Yearly Throughput (box)		40F Yearly Throughput (box)	
	Scenario 5	Scenario 6	Scenario 5	Scenario 6
Location 1	14,809	14,809	11,106	11,106
Location 2	5,617	5,617	4,213	4,213
Location 3	8,063	8,063	6,048	6,048
Location 4	14,318	7,276	10,739	5,457
Location 5	16,714	0	12,535	0
Location 6	12,763	8,152	9,572	0
Location 7	5,132	5,132	3,849	3,849
Location 8	2,489	2,489	1,867	1,867
Location 9	3,398	3,398	2,549	2,549
Location 10	0	0	0	0
Location 11	0	0	0	0

Transfer Point Location	20F Yearly Throughput (box)		40F Yearly Throughput (box)	
	Scenario 5	Scenario 6	Scenario 5	Scenario 6
Location 12	5,538	5,538	4,154	4,154
Location 13	781	0	586	0
Location 14	7,471	7,471	5,604	5,604
Location 15	7,578	7,578	5,683	5,683
Location 16	9,355	9,355	7,017	7,017
Location 17	9,964	9,964	7,473	7,473
Location 18	8,125	8,125	6,094	3,880
Location 19	0	0	0	0
Location 20	0	0	0	0
Location 21	7,869	7,869	5,902	5,902
Location 22	6,287	6,287	4,715	4,715
Location 23	6,889	6,889	5,167	5,167
Location 24	3,846	3,846	2,885	2,885
Location 25	0	0	0	0
Location 26	0	0	0	0

In general, the result of this situation is the same as the previous situation. Six locations (Location 10, 11, 19, 20, 25 and 26) are not optimum to deliver any freight because of high transport cost if the OD combination uses those locations. Three locations (Location 5, 6 and 13) are partially utilized because they are eligible for transporting freight in scenario 5 but still more expensive than using road, as proved in scenario 6. The total throughput of both situations can be seen in Table 7-7. The optimum location for transfer points that spread across Port of Tanjung Emas hinterland based on the optimum solution in the model can be seen in Figure 7-4 and the preference of each gravity point for transport network system in attraction situation can be seen in Table 7-8.

Table 7-7 Total Predicted Freight Throughputs between Scenarios for Every Transfer Point

Transfer Point Location	20F Yearly Throughput (box)		40F Yearly Throughput (box)	
	Scenario 2&5	Scenario 3&6	Scenario 2&5	Scenario 3&6
Location 1	33,063	33,063	24,797	24,797
Location 2	12,711	12,711	9,533	9,533
Location 3	17,764	17,764	13,324	13,324
Location 4	31,773	16,352	23,831	12,265
Location 5	34,419	0	25,815	0
Location 6	27,397	17,037	20,548	0
Location 7	11,299	11,299	8,475	8,475
Location 8	5,510	5,510	4,133	4,133
Location 9	7,543	7,543	5,658	5,658
Location 10	0	0	0	0

Transfer Point Location	20F Yearly Throughput (box)		40F Yearly Throughput (box)	
	Scenario 2&5	Scenario 3&6	Scenario 2&5	Scenario 3&6
Location 11	0	0	0	0
Location 12	12,500	12,500	9,376	9,376
Location 13	1,609	0	1,207	0
Location 14	16,262	16,262	12,197	12,197
Location 15	16,632	16,632	12,474	12,474
Location 16	20,296	20,296	15,223	15,223
Location 17	21,869	21,869	16,403	16,403
Location 18	18,244	18,244	13,683	8,733
Location 19	0	0	0	0
Location 20	0	0	0	0
Location 21	16,366	16,366	12,275	12,275
Location 22	13,378	13,378	10,034	10,034
Location 23	15,205	15,205	11,404	11,404
Location 24	8,598	8,598	6,449	6,449
Location 25	0	0	0	0
Location 26	0	0	0	0

Table 7-8 Preference of Transport Network System for Each Gravity Points in Attraction Situation

Gravity Point	Preferred Network System	
	20F	40F
Kota Tegal	IFT	IFT
Brebes	IFT	IFT
Pemalang	IFT	IFT
Kota Pekalongan	IFT	IFT
Batang	IFT	IFT
Kendal	Truck	Truck
Kota Semarang	Truck	Truck
Demak	Truck	Truck
Kudus	IFT	Truck
Pati	IFT	IFT
Jepara	IFT	Truck
Rembang	IFT	IFT
Blora	IFT	IFT
Purwodadi	IFT	IFT
Sragen	IFT	IFT
Surakarta	IFT	IFT
Karanganyar	IFT	IFT

Gravity Point	Preferred Network System	
	20F	40F
Boyolali	IFT	IFT
Salatiga	Truck	Truck
Kab. Semarang	Truck	Truck
Kota Magelang	Truck	Truck
Temanggung	Truck	Truck
Wonosobo	IFT	IFT
Banjarnegara	IFT	IFT
Purbalingga	IFT	IFT
Purwokerto	IFT	IFT
Purworejo	IFT	Truck
Kebumen	IFT	IFT
Cilacap	IFT	IFT
Magelang	Truck	Truck
Kab. Pekalongan	IFT	IFT
Kab. Tegal	IFT	IFT
Bantul	IFT	IFT
Gunungkidul	IFT	IFT

Gravity Point	Preferred Network System			Gravity Point	Preferred Network System	
	20F	40F			20F	40F
Wonogiri	IFT	IFT		Kuloprogo	IFT	IFT
Sukoharjo	IFT	IFT		Sleman	IFT	IFT
Klaten	IFT	IFT		Kota Yogyakarta	IFT	IFT

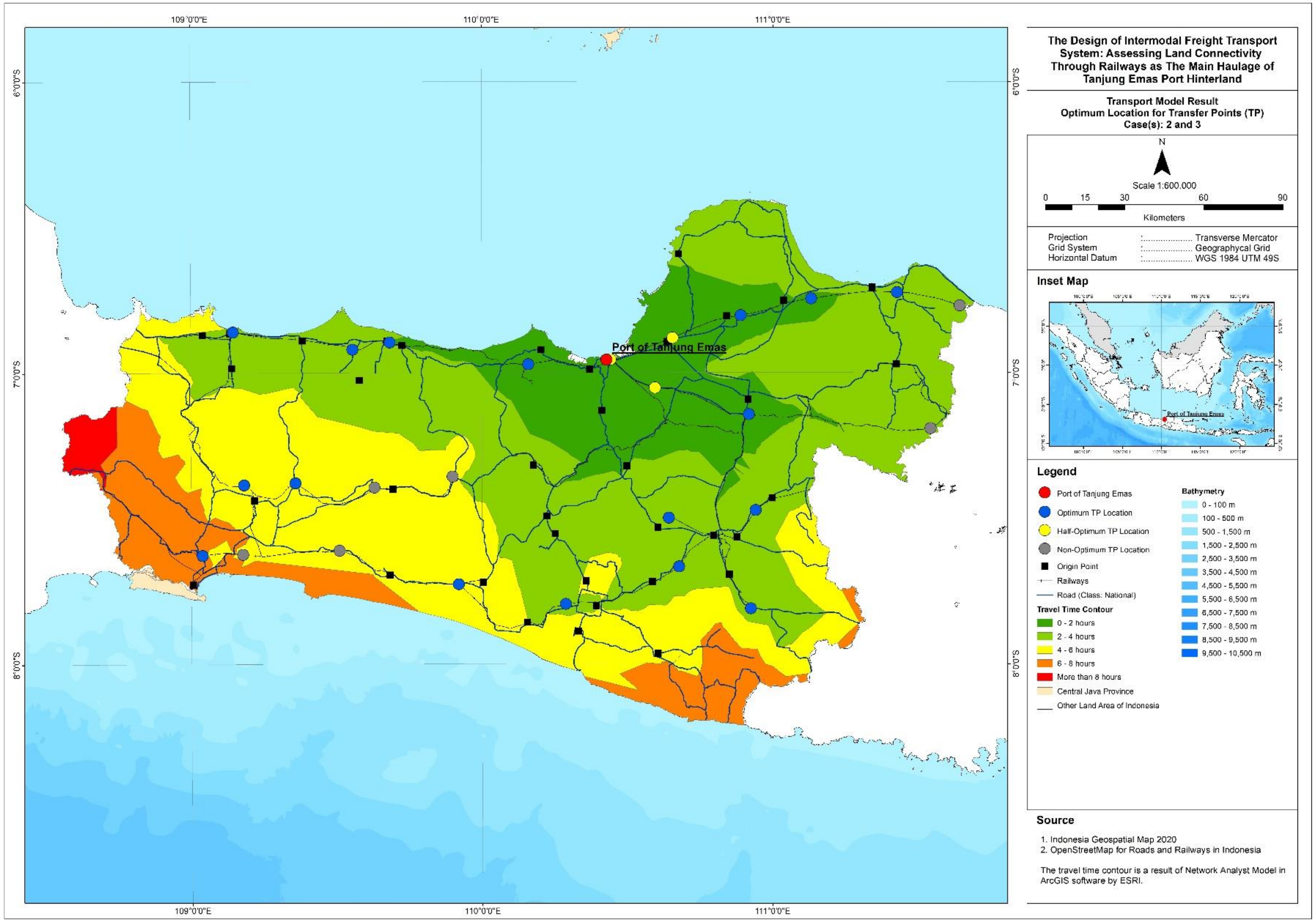

Figure 7-4 The Optimum Location for Transfer Points in Production Case Based on Transport Model

Chapter 8. Discussion and Conclusion

The previous chapter already provided results of the travel time and network transportation models in regard to assessing intermodal accessibility in Port of Tanjung Emas hinterland. The travel time model shows that the total time for any random freight from gravity points of PoTE hinterland to the port, or the other way around, will increase significantly especially because of additional handling time in transfer points. On the other hand, the total transport cost will decrease as implementation of IFT system in the PoTE hinterland is sufficient enough to accommodate the requirement of optimum distance for the intermodal system. This chapter takes a closer look at the simulation results of both models and connects the dots between their theoretical and practical meaning. The limitation of those models and the recommendation to improve further research are also considered as important things to discuss and displayed in the later part of this chapter.

8.1. Concluding Remarks

The road traffic conditions in Central Java, especially in Semarang City where Port of Tanjung Emas resides, is getting denser because of huge traffic load and increase of population. Taking aside the congestion problem, world transportation business trends of shifting their operational from a conservative method to a greener transportation system is getting more intense in regard to zero carbon emission program and other global agenda to conserve this world of living. Those reasons are enough to be concluded as foundation for transportation business to seek any alternative for their current system. Therefore, with all of reasons and problems, we developed this research main question into "How do railways improve Port of Tanjung Emas connectivity to its hinterland?."

As a response to the research main question, we also addressed four sub-research questions to help creating a better understanding of solution to the mentioned problems. The first sub-research question is "What is the role of railway in freight transport system of Central Java?." In Chapter 4, we discuss the connectivity and accessibility of Tanjung Emas Port to its hinterland. The railways currently have minimum impact on freight transport in PoTE hinterland because the port is not designed to manage or accommodate freight transport by train for the majority of its hinterland. This condition is critical because this port needs supporting infrastructure of managing the freight from more than one mode in order to assess its ability for implementing intermodal freight transport system. Along the investigation of railways network system in Central Java, we found that the railways route to Port of Tanjung Emas already existed, but the lines only serve passenger train. Even though the railway lines are pretty much useless for freight transport right now, we try to assess the IFT system by using the existing railways in order to illustrate the impact of using trains as transportation mode of freight.

The second sub-research question wonders about the performance of PoTE. Port of Tanjung Emas has a mildly huge throughput compared to majority ports in Indonesia, but still has less throughput than its two competitors in Northern part of Java Island, which are Port of Tanjung Priok and Tanjung Perak. In 2021, Port of Tanjung Emas served 855,994 TEU. Due to increasing GDP and population trends of Indonesia in general and specifically Central Java, the container throughput is forecasted to increase in coming years. The confidence of increasing PoTE throughput not only comes from the mentioned trends but also from the development of industrial zones in PoTE hinterland. This reason should boost the awareness of finding alternative transport systems for serving the need of container transport within the port hinterland.

Furthermore, the third sub-research question is about “How is Port of Tanjung Emas` existing connectivity to its hinterland?.” Chapter 4 explains about the connectivity conditions of PoTE to its hinterland. Currently, freight trucks dominate the freight transport within the port hinterland, and it is becoming a concern because of congestion issues across Central Java, especially near Semarang City where the majority business in Central Java happens. To take it into statistical perspective, freight transportation business in Indonesia still uses freight truck in a bit more than 90% of total freight traffic. Huge construction of freeway is already on-going across Central Java Province but the congestion issues that happen nearby Semarang City will be less benefited with the current development of freeway because of the traffic load and the city purpose as the epicenter of business in Central Java. Hence, the hypothesis of alternating or diverting the current traffic load to other modes is developed.

The fourth sub-research question discussed the connectivity comparison between existing network and planned IFT network in terms of efficiency. To answer this question, this research develops two models to illustrate the comparison between those two kinds of network. The first model illustrates the general travel time for each network system in PoTE hinterland and the second model uses network transportation model in order to calculate the overall travel cost for specific port throughput and to find optimum routing for intermodal freight transport system. Those models are static models, which emerge as a basis understanding of systems comparison before planning more technical model for operational matters in the further stage of research. Thus, this research can state the advantages and disadvantages of both systems in general with comparison of travel time contours and objective value from each scenario as basis of argument.

The result from travel time model provides difference between existing condition with truck as its main haulage and intermodal system which treats freight train as main haulage for transporting containers from/to Port of Tanjung Emas. Although the overall duration of freight movement decreased by implementing IFT system, the actual duration of transporting freight will be increased if the calculation considers the handling time in the transfer points. The result of the network transport model shows a decrease in objective value by implementing the IFT system. In production situation, the objective value decreases by 8.20% - 8.68% and in attraction situation, the objective value decreases by 8.05% – 8.61%. The best result for objective value comes from combining the unimodal and intermodal transportation system, as longer distance gravity points will be served by combination of truck and train while shorter distance gravity points will be served by truck only.

Finally, we emphasize our findings from both models to answer our main research question. The network transportation model shows a remarkable improvement in land connectivity of Tanjung Emas Port by introducing railway as an alternative for transporting freight. The IFT system can absorb part of road traffic loads which are produced by freight trucks in regard to lower transportation cost. As most of gravity points tend to choose IFT system for transporting their freights, the further area of PoTE hinterland can rely more on IFT system due to its higher efficiency for longer distance transportation. The intermodal transport system can enhance the connection between Port of Tanjung Emas and its hinterland as it creates an extra choice to reach the port with a lower transportation cost from current transport system for most of the gravity points in the port hinterland. The travel time map can be useful to estimate the arrival time of freight. Although this map needs to be improved with handling and waiting time estimation, the general clustering is robust enough to illustrate the estimation of moving time.

8.2. Theoretical and Practical Implications

The model framework and equations we developed for both models have successfully illustrated the general condition of implementing IFT system in PoTE hinterland. The travel time maps can estimate PoTE in-land service area but needs to be improved by inserting the handling time of its transfer points. The network transport model shows ample evidence of benefit in applying the IFT system as the overall transportation cost decreases from the current network system. The result from network transport model confirms the effectiveness of IFT system in long distance haulage, as the gravity points near PoTE choose to do truck haulage rather than intermodal system as it is cheaper to do so while the longer distance gravity points tend to choose to mount the container on freight trains. By combining the results from those two models—implementing IFT system will decrease the overall transportation cost and increase the travel time—we successfully synchronized the mentioned theory from Li *et al.* (2023) in this research.

The model framework of network transport model was created based on IFT system components as explained in The Geography of Transport System from Rodrigue (2020). This fundamental concept of clustering the network components is a decent method to understand the mechanisms and entities behind transport systems. The Rodrigue fundamental network components consist of *composition* or first mile as we put all gravity points of PoTE in this role, *transfer* as we use both road and railway network to build the overall transfer route, *interchange* as we put every transfer point to be this part, and Port of Tanjung Emas as *decomposition* or last mile. Each component has its own role and specific equation and variables of cost that any researcher can develop depending on the case they face. In this research, we put handling cost in first mile, interchange, and last mile components as cost variable and movement cost per distance unit in transfer component. As we found in data gathering phase in this research, the main difference between road and railway transport is that railway transport has lower movement cost per distance unit but has an extra handling cost due to change of mode in interchange component. This additional cost can be exceeded by lower cost of train movement with longer voyage distance. Hence, it creates the notable strength of intermodal system, which is IFT system can reduce the freight transport costs over long-distance transport (refers to Table 2-1 of strength analysis for IFT system).

The network transport model also provides the optimum routing for the planned IFT system. While this model uses 26 transfer point locations as locations for shifting mode in IFT system, the result determines only 20 of them are optimum for transporting the freight due to cost efficiency. As the model calculates further to ultimate scenario—which each gravity point can choose between unimodal and intermodal cost-wise—3 of 20 transfer points are no longer optimum locations. Those 3 locations are located close to Port of Tanjung Emas, which indicates the gravity points near PoTE tend to choose truck haulage to transport their freight. As the ultimate result of the optimum routing analysis from this network model, 17 optimum transfer points for IFT systems in PoTE hinterland are suggested for the planned IFT network system and can be seen in Figure 7-4.

The preference of choosing network system for each gravity point shows 8 out of 40 gravity points tend to choose truck/road transport as their main haulage instead of IFT system, while the other 2 gravity points choose truck/road transport for their 40F containers and IFT system for 20F containers (these information can be seen in Table 7-4 and Table 7-8). As the result provides information of 77.5% of total combination of gravity points and container types tend to choose IFT system under cost considerations, with a decrease of 8.65% of total transportation cost for both production and attraction situations, we can safely assume that PoTE hinterland will be benefited in overall transportation cost if the hinterland implements the IFT network transport system.

8.3. Limitation

Every research project is inevitably going to have some restrictions, no matter how precisely it is planned or conducted. The travel time model in this research shows a credible result of total moving time but it cannot describe the total transport time of freight due to limitation in gathering information of handling time for every transport point. The handling time of transfer point is a missing piece of this model to get a remarkably close generalization of travel time clusters in PoTE hinterland, but a half-decent approach might lead to misinterpretation of the model. For this specific reason, we avoided using a general approach for handling time.

The railway network of PoTE hinterland uses the existing network of railways for passenger trains, so does the transfer points. This assumption exceeds the technical feasibility of both components. Speaking about technical aspects, both models in this research only use national class road to model the optimum route of freight truck. Those assumptions were being used in order to limit the complexity of transportation conditions. In fact, the existing route of freight truck might be different to the model because of the existence of lower-class roads which are still passable by freight truck.

Another assumption we use in the model is that network transport model exempts the time cost variable in calculating the overall transportation cost. The time cost variable can be significant in reality due to fluctuation of traffic and other uncertain circumstances. There are several cost variables that could be added in the calculation depending on the circumstances and research objectives. In addition, deeper understanding of transport conditions in the research area should benefit the cost estimation calculations and the calculation can represent the reality better.

8.4. Recommendation for Future Research

Since the demand of alternative network systems is remarkably high nowadays in transportation business, the main obstacle in modelling the network system arose during the data gathering phase and assembles the gathered information into a realistic scenario. Although the reality is too complicated to be modelled, the best researcher can do is to estimate it as close as it gets. While setting up the scenarios and models, some approach could not be done due to limitation of data and information. Hence, we recommend the future research to use as many cost variables as it can such as time cost and environmental cost. The travel time model also missed some variables such as handling time and waiting time. It is also important for the further and following researches to consider the potential competition from other ports. In our case, the competitiveness is exempted due to the behavior of static model and early stage of network analysis as explained by Van Duin and Ham (1998). Thus, the further part of network analysis can use the dynamic model to get more understanding of IFT system.

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B. Appendix

R Code for Network Transport Model

```
#DATA WRANGLING#

data <- file %>%
  readxl::excel_sheets () %>%
  purrr::set_names() %>%
  purrr::map(readxl::read_excel, path = file)

wrangling <- function(data){

  Freight <- dplyr::filter(data$Nodes, Entity == "Freight")$Name
  Origin <- dplyr::filter(data$Nodes, Entity == "Origin")$Name
  Intermediary <- dplyr::filter(data$Nodes, Entity == "Intermediary")$Name
  Destination <- dplyr::filter(data$Nodes, Entity == "Destination")$Name

  cost_in <- dplyr::filter(data$Cost, type == "in")

  incost <- array(
    as.matrix(cost_in$value),
    dim = c(length(Freight), length(Origin), length(Intermediary)),
    dimnames = list(Freight, Origin, Intermediary)
  )

  cost_out <- dplyr::filter(data$Cost, type == "out")

  outcost <- array(
    as.matrix(cost_out$value),
    dim = c(length(Freight), length(Intermediary), length(Destination)),
    dimnames = list(Freight, Intermediary, Destination)
  )
```

```
# transfer point capacity
Int_Capacity <- matrix(
  dplyr::filter(data$Capacity, Node == "Intermediary")$Value,
  ncol = 1,
  dimnames = list(Intermediary, "Int_Capacity")
)

# total supply of every municipality
Ori_Total <- matrix(
  dplyr::filter(data$Capacity, Node == "Origin")$Value,
  ncol = 1,
  dimnames = list(Origin, "Ori_Total")
)

# supply of every kind of container for each municipality
Box_Supply <- array(
  dplyr::filter(data$NodeARCs, Type == "Supply")$Value,
  dim = c(length(Origin), length(Freight)),
  dimnames = list(Origin, Freight)
)

# destination capacity or just use known throughput
Demand <- array(
  dplyr::filter(data$NodeARCs, Type == "Demand")$Value,
  dim = c(length(Destination), length(Freight)),
  dimnames = list(Destination, Freight)
)

return(
  list(
    Freight = Freight,
    Origin = Origin,
    Intermediary = Intermediary,
    Destination = Destination,
```

```
      incost = incost,
      outcost = outcost,
      Int_Capacity = Int_Capacity,
      Ori_Total = Ori_Total,
      Box_Supply = Box_Supply,
      Demand = Demand
    )
  )
}

ready_data <- wrangling(data)

#------------------------------------------------------------------------------#
#SETTING UP MODEL#

# CREATE DUMMY INTERMEDIARIES FIRST FOR UNIMODAL COST ESTIMATION
transport_model <- function(
    Freight, Origin, Intermediary, Destination, incost, outcost,
    Int_Capacity, Ori_Total, Box_Supply, Demand) {

  require(ROI)
  require(ROI.plugin.glpk)

  i <- length(Freight)
  j <- length(Origin)
  k <- length(Intermediary)
  l <- length(Destination)

  model <- ompr::MIPModel() %>%

    # inflow variable
    ompr::add_variable(xinf[i,j,k], i = 1:i, j = 1:j, k = 1:k,
                       type = "integer", lb = 0) %>%
```

```
  # outflow variable
  ompr::add_variable(xout[i,k,l], i = 1:i, k = 1:k, l = 1:l,
                     type = "integer", lb = 0) %>%

  # objective function
  ompr::set_objective(
    ompr::sum_expr(xinf[i,j,k] * incost[i,j,k], i = 1:i, j = 1:j, k = 1:k) +
      ompr::sum_expr(xout[i,k,l] * outcost[i,k,l], i = 1:i, k = 1:k, l = 1:l),
    sense = "min"
  ) %>%

  # origin production capacity for each box type
  ompr::add_constraint(ompr::sum_expr(xinf[i,j,k], k = 1:k) <=
                         Box_Supply[j,i], i = 1:i, j = 1:j) %>%

  # origin total production capacity
  ompr::add_constraint(ompr::sum_expr(xinf[i,j,k], i = 1:i, k = 1:k) <=
                         Ori_Total[j], j = 1:j) %>%

  # intermediary capacity
  ompr::add_constraint(ompr::sum_expr(xinf[i,j,k], i = 1:i, j = 1:j) <=
                         Int_Capacity[k], k = 1:k) %>%

  # total port throughput
  ompr::add_constraint(ompr::sum_expr(xout[i,k,l], k = 1:k) >=
                         Demand[l,i], i = 1:i, l = 1:l) %>%

  # flow constraint
  ompr::add_constraint(
    ompr::sum_expr(xinf[i,j,k], j = 1:j) == ompr::sum_expr(xout[i,k,l], l = 1:l),
    i = 1:i, k = 1:k
  )

# solving model
```

```
result <- ompr::solve_model(model, ompr.roi::with_ROI(solver = "glpk"))

# result
objective <- result$objective_value

infl <- ompr::get_solution(result, xinf[i,j,k]) %>%
  dplyr::mutate(freight = Freight[i], source = Origin[j],
                destination = Intermediary[k], type = "Inflow") %>%
  dplyr::select(type, freight, source, destination, value)

outfl <- ompr::get_solution(result, xout[i,k,l]) %>%
  dplyr::mutate(freight = Freight[i], source = Intermediary[k],
                destination = Destination[l], type = "Outflow") %>%
  dplyr::select(type, freight, source, destination, value)

int_flow <- infl %>%
  dplyr::group_by(destination, freight) %>%
  dplyr::summarise(Amount = sum(value)) %>%
  as.data.frame()

ori_freight <- infl %>%
  dplyr::group_by(source, freight) %>%
  dplyr::summarise(Amount = sum(value)) %>%
  as.data.frame()

freight_flow <- rbind(infl, outfl)

return(
  list(
    objective = objective,
    inflow = infl,
    outflow = outfl,
    freight_flow = freight_flow,
    int_flow = int_flow,
```

```
      origin_freight = ori_freight
    )
  )
}

model <- transport_model(
  Freight = ready_data$Freight,
  Origin = ready_data$Origin,
  Intermediary = ready_data$Intermediary,
  Destination = ready_data$Destination,
  incost = ready_data$incost,
  outcost = ready_data$outcost,
  Int_Capacity = ready_data$Int_Capacity,
  Ori_Total = ready_data$Ori_Total,
  Box_Supply = ready_data$Box_Supply,
  Demand = ready_data$Demand
)
```