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Reliability of Road and Rail Transportation in the Distribution of Goods Commodities on the Makassar-Parepare Route

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ABSTRACT

The transportation of goods in South Sulawesi remains predominantly reliant on road networks, with truck transport playing a central role in the region's logistics. Despite the introduction of rail infrastructure, its effectiveness as an alternative freight transportation mode has not been comprehensively evaluated. This study assesses the reliability, cost-efficiency, and environmental impact of both truck and rail transport along the Makassar–Parepare route, employing both qualitative and quantitative methodologies. The findings reveal that road transport demonstrates superior reliability and operational flexibility, with trucks offering lower transportation costs at IDR 404 per ton-kilometre, compared to IDR 511 per ton-kilometre for rail. However, rail transport exhibits increasing cost efficiency over longer distances, particularly beyond 360 kilometres. A modal shift of 30% from trucks to rail has the potential to reduce carbon emissions by 22.6%, contributing to environmental sustainability through a 29.5% reduction in fuel consumption. These results highlight the need for an integrated approach to transport infrastructure development, where economic, environmental, and social dimensions are holistically addressed. Future efforts to enhance rail infrastructure could provide significant long-term benefits by alleviating road congestion and supporting sustainable freight transportation.

1. INTRODUCTION

In the logistics system, trucks and trains are important modes of freight transportation, each with its own advantages and disadvantages. Trucks are the dominant mode of freight transportation, especially for short to medium distances, as they offer flexibility and accessibility [1]. However, trucks have drawbacks when it comes to emissions and environmental concerns due to their reliance on diesel engines [2]. On the other hand, trains are known for their fuel efficiency and lower emissions compared to trucks [3]. The choice between trucks and trains for freight transportation depends on various factors, including distance, cost, and environmental impact. Research shows that trucks consume most of the total energy used in freight transport, and most of it is used by freight trucks and trains in the transportation sector [3]. While trucks are efficient for short distances, rail is more suitable for long-distance transportation, as it offers higher energy efficiency and lower emissions per ton-mile [4]. Intermodal freight transport, which combines various modes, including trucks and trains, has been proposed to improve the efficiency and reliability of freight transportation [5]. Reliability is an important aspect of freight transportation, impacting supply chains and economic activity. Trucking freight rates have strong predictive power against other transportation freight rates and key economic indicators [6]. However, resistance from aspects such as highway congestion and operational safety can affect the reliability and competitiveness of trucking [7]. Utilizing truck GPS data has proven to be beneficial in generating reliable measures of freight performance, ultimately improving the efficiency and reliability of truck operations [8].

Trucks have an important role in the transportation of goods in Indonesia; most of the daily needs, such as basic and essential goods, are transported by trucks, buses, and other vehicles [9]. Land freight transportation in Indonesia faces challenges related to overloaded trucks, which account for more than 60% of the total trucks in use today, impacting the efficiency and reliability of truck transportation and causing road damage [10]. Several studies on rail and truck use in the United States highlight the potential reliability and competitiveness of freight transportation based on mode [7]. In some cases, overloaded trucks can be integrated between different modes of transportation, such as rail and truck, thus significantly improving the reliability of freight transportation.

To compare trucks and trains for freight transportation in South Sulawesi Province, particularly on the Makassar-Parepare route, it is important to consider factors such as cost, efficiency, and environmental impact. Trucks are commonly used for short-distance transportation in South Sulawesi due to their flexibility and accessibility [11]. However, trucks can be affected by traffic and weather conditions, potentially impacting their reliability [12]. On the other hand, trains are known for their energy efficiency and lower emissions compared to trucks, making them suitable for long-distance travel. Research [13] shows that freight train transportation requires less energy and produces fewer emissions compared to truck transportation.

In South Sulawesi, the operational cost of freight transportation is an important consideration because most service users are more concerned with transportation costs than other factors. Research [14] has analyzed the cost of transporting containers using trucks, trains, and sea transportation modes in South Sulawesi, revealing significant differences in the use of these modes. Each mode has advantages based on service distance. The results of this analysis can provide information on the cost-effectiveness of various modes of transportation in South Sulawesi.

The implications of using trains instead of trucks for freight transportation in South Sulawesi are expected to have a significant impact on the effectiveness and efficiency of the logistics system. Rail offers a more sustainable and efficient mode of transportation, with one train able to replace 35 to 100 trucks, thereby reducing road traffic and associated congestion [15]. Switching to rail transportation can lower freight rates between regions, benefiting the economy and reducing transportation costs [16]. Utilizing the advantages of rail transportation over road transportation, the logistics system in South Sulawesi can improve the reliability, cost-effectiveness, and sustainability of freight transportation. The safety and efficiency of land terminals connected to the rail transportation system can be improved and ensure the safe handling of dangerous goods [15]. In addition, the implementation of rail transportation can provide economic benefits and improve logistics operations in a region, thereby mitigating the high tariffs associated with road transportation between regions [16].

The shift of cargo from truck transport to rail mode on the Makassar-Parepare route has a significant impact in the context of the logistics transportation system in South Sulawesi. The use of trains can reduce the burden of traffic on roads, reduce congestion, and improve transportation safety. This will result in a more efficient and sustainable transportation system and reduce exhaust emissions and other negative environmental impacts generated by truck transportation. In addition, rail is more efficient in transporting large volumes of goods over long travel distances, which can reduce overall transportation costs. However, the shift to rail transportation may also pose new logistics challenges, such as coordinating the transfer of goods from rail terminals to end points, requiring proper infrastructure and operational processes. In addition, rail may be less flexible in terms of schedules and routes compared to truck transportation, which may affect the responsiveness and flexibility of deliveries. Therefore, this transition will require careful planning and effective integration between different modes of transportation to ensure efficiency and success in the overall logistics transportation system.

The presence of rail transportation modes in South Sulawesi represents a viable alternative for the distribution of logistics commodities. Several references suggest that the logistics transportation system with rail mode has advantages in terms of economic and environmental aspects; on the other hand, road truck transportation that is currently developing is used by transport service providers to increase profits, causing over-dimensional and overload (ODOL) problems that lead to road damage, fuel waste, and exhaust emissions related to public health. Based on this problem, the following research questions were formulated:

a) What is the comparative value between road and rail transportation truck modes from the economic aspects of transportation costs?

b) What are the advantages of each mode in terms of economic, social, and environmental sustainability?

2. RESEARCH METHODS

2.1 Type and location of research

This research is a combination of quantitative and qualitative research based on comparisons, analyzing the characteristics of the movement of commodity goods from Makassar towards Parepare and vice versa, and evaluating the reliability of the use of road-based and rail-based transportation. The research location and data collection can be seen in Figure 1.

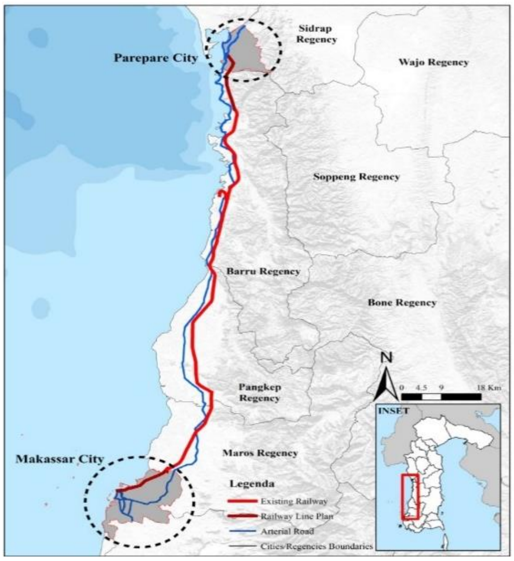

Figure 1. Research location

2.2 Population and sampling

The population of this study is the number of freight vehicles that move from Makassar City to Parepare City and vice versa. Sampling was done on 358 vehicle owners to be used as research samples. A total of 179 cars traveled from Makassar to Parepare and from Parepare to Makassar.

The sample size of 358 vehicles was chosen by considering population characteristics, sampling methods, and statistical parameters. The population of goods vehicles on the Makassar-Parepare route is estimated at 1,500 vehicles per week, so this sample is considered representative. The purposive sampling method was used to cover the variety of vehicles based on the type of goods transported, vehicle type, and wheelbase configuration. In addition, this sample size was based on statistical calculations with a 95% confidence level and a margin of error of ±5%. Therefore, this sample is capable of yielding valid and accurate results when describing the conditions of goods distribution along the route.

Goods vehicles that use road transportation have different characteristics, so this study focuses on vehicles with the most widely used types and axis configurations as shown in Table 1.

Table 1. Configuration of the studied vehicle axle loads [17]

Axis Configuration and Type	Empty Weight (tons)	Maximum Load (tons)	Maximum Total Weight (tons)	EU 18 Chief of Naval Staff Vacant	Maximum UE KSAL
1.1 HP	1.5	0.5	2.0	0.0001	0.0004
1.2L Truck	2.3	6	8.3	0.0013	0.2174
1.22 Truck	5	20	25	0.0044	2.7416
1.2-22 Trailer	10	32	42	0.0327	10.183

Notes: 1 kilopond Kilonewton=101.9 Kg; equivalent unit 18 KP, single axial load (EU 18 KSAL)

2.3 Data collection

Data is sourced from primary data and secondary data. Primary data collection is carried out on samples of goods transportation vehicles whose direction of movement is from Makassar City to Parepare City and vice versa. Vehicle data collection was carried out in 3 areas, namely the Wholesale Trade Area (among others on Sulawesi Street, Kalimantan Street, Nusantara Street, and Panampu Street), Industrial and Warehousing Area 'KIMA', and the area around the port of Makassar) in Makassar City. Data collection locations in Parepare City are focused on industrial areas and road interviews. It is assumed that the movement of vehicles from Makassar to Parepare is represented by vehicles in Makassar City, while the movement from Parepare to Makassar City is represented by vehicles originating from Parepare City.

To ensure the quality and accuracy of the data during the collection process, data were validated with multiple sources through verification with weighbridge data in Maccopa Maros and weighbridge data in Sidenreng Rappang. The data collection instrument (semi-closed questionnaire) was standardized and pre-tested. The pilot test was conducted to ensure that the questions were easily understood by respondents and that they captured relevant data. Each questionnaire was controlled to include all required indicators, such as vehicle type, load, and trip frequency. During the field data collection process, the data collection team was given special training to ensure they understood the data collection procedures correctly, including interview techniques, questionnaire completion, and field observation methods. This was done to minimize human errors during the data collection process.

Other data in the form of railway operational plans were sourced from the railway feasibility study of the Directorate General of Railways of the Ministry of Transportation in 2012.

2.4 Data analysis

The expert assessment in this study was carried out by involving 12 experts who were selected based on their expertise in the field of goods transportation, especially in truck and train modes. The experts involved include 4 transportation regulators, 3 (three) logistics operators, 3 (three) users of transportation services, and 2 (two) academics who have research experience related to the distribution of goods and the reliability of transportation modes.

The method used was semi-structured in-depth interviews, where each expert was asked a list of open-ended questions regarding reliability, flexibility, supply chain visibility, transportation costs, cost savings, and carbon emissions for both modes of transportation (explanation in Table 2). Interviews were conducted face-to-face and online, lasting between 60 and 90 minutes each. All interviews were recorded and transcribed verbatim to ensure no information was lost or overlooked.

After data collection, the content analysis method was used to categorize expert responses into several main thematic categories. For example, the assessment of reliability was based on responses related to travel time, trip frequency, and operational stability. Similarly, the assessment of flexibility was based on the mode's ability to adjust to changes in demand and door-to-door load handling.

The qualitative results from these interviews were then compared with the quantitative data to provide a more comprehensive conclusion on the reliability of truck and rail transportation modes. The level of consensus among experts was also analyzed by calculating the frequency of similar responses; for example, 83% of experts stated that trucks are superior in terms of flexibility, while 67% stated that trains are more environmentally friendly in the long run.

Table 2. Criteria for freight transportation reliability indicators

Criteria	Description	References
Reliability	The ability to provide a quality level of service in delivering products in the supply chain effectively and has an influence on travel time and frequency	[18-21]
Flexibility	The ability of transportation modes to deal with demand uncertainty, and offer higher capacity, as well as distribution flexibility (door to door)	[19-22]
Supply chain visibility	Ability for customers to identify location and delivery status tracking to be more responsive	[22, 23]
Total transportation cost	The amount of costs that must be incurred by the owner of the goods for transportation services (IDR/ton)	[21, 22]
Freight cost savings	The value of savings obtained if there is a shifting from truck to rail transportation in a certain period (IDR. ton/km)	[24, 25]
Fuel savings	The value of fuel savings obtained if there is a shifting from truck to rail transportation in a certain period (IDR. litter/ton)	
Carbon emissions	Amount of Carbon Emissions generated (tons)	[2, 3, 26]

3. RESULTS AND DISCUSSION

3.1 Freight distribution pattern

The distribution pattern of the movement of origin and destination of goods is transported by road transportation. In this study, the distribution pattern of goods on the Makassar-Parepare route is dominated by vehicle movements originating from industrial and warehousing areas by 57%, the Pannampu area and its surroundings by 36%, while those originating from the port are around 7%. The majority of vehicle movements originate from the Makassar area, accounting for 55%, followed by other regencies/cities in South Sulawesi at 29%, and outside South Sulawesi at 16%.

The distribution pattern of goods on the Parepare-Makassar route is dominated by vehicles originating from other districts or cities in South Sulawesi by 73.2%, vehicles from Parepare City (Suppae Area, KIPAS, and Parepare Port) by 15.1%, and vehicles originating from outside South Sulawesi by 11.7%. The purpose of vehicle movements from the direction of Parepare mostly leads to Warehousing 53.5%, Makassar Port 14.0%, Industrial Area 10.6%, other areas within Makassar city 17.9%, and Gowa Regency 3.9%. Vehicle movements surveyed in the direction of Makassar-Parepare and vice versa can be seen in Table 3.

In addition to the distribution pattern formed by the origin of the movement destination, the freight transportation pattern also has specific characteristics. On the Makassar-Parepare route, vehicle transportation is dominated by warehouse-to-door transportation patterns (40.8%), while the lowest is the movement from door to door and door to warehouse, ranging from 8.4%. Likewise, on the Parepare-Makassar route, the dominant transportation pattern is warehouse-to-warehouse (54.7%), and the lowest is the movement from warehouse to door, around 8.9% (see Figure 2).

Table 3. Origin-destination of truck vehicle movement (unit)

Origin - Destination	KIMA Makassar	Pannampu and Surroundings	Makassar Port and MNP	Makassar (Within City)	Suppae Area	Parepare Industrial Estate	Parepare Port	Gowa	Regencies/Cities in South Sulawesi	Regencies/Cities Outside South Sulawesi	Number of Destination
KIMA Makassar				34		8			31	29	102
Pannampu and Surroundings				2	3				53	6	64
Makassar Port and MNP	7			2		1			3		13
Makassar (Within City)											
Suppae Area	4	1		5							10
Parepare Industrial Estate	1										1
Parepare Port	6	1	1	7				1			16
Gowa											
Regencies/Cities in South Sulawesi	64	7	10	50							131
Regencies/Cities Outside South Sulawesi	8		2	9				2			21
Number of Destination	90	9	13	109	3	9		3	87	35	358

Source: Analysis results, 2024

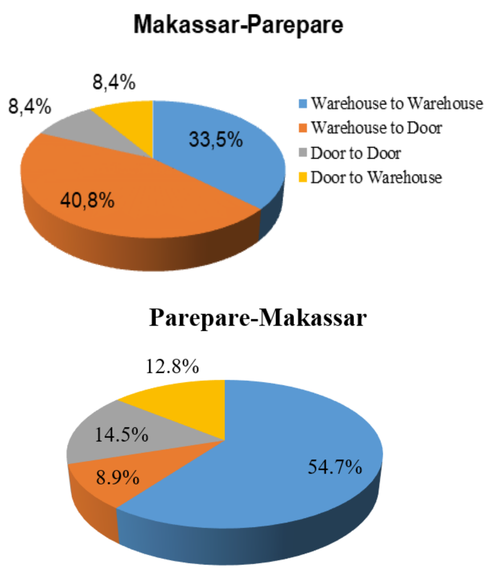

Figure 2. Vehicle transportation pattern

Predominantly door-to-door or warehouse-to-door distribution tends to be more suitable for truck transportation due to its flexibility. Trucks can directly deliver goods to various destinations without the need for additional handling, making them more reliable in terms of delivery frequency and shorter travel time (around 3-4 hours). With this distribution pattern, trucks are able to adjust to changes in demand and field conditions, providing great flexibility for shippers.

Railways, while superior in terms of carrying capacity and reduced cost and carbon emissions over longer distances, face challenges in this distribution pattern. Trains require additional processes, such as feeder transportation from the station to the warehouse or end customer, which can add time and cost. The warehouse-to-warehouse distribution pattern on the Parepare-Makassar route, for which trains are more suitable, only covers about 54.7% of the total distribution, while the door-to-door pattern, which is more profitable for trucks, is more dominant.

This condition cause's road transportation will certainly still be the main priority of business actors in the process of distributing goods in the future. The amount of transportation patterns from warehouse to door, or those that start and end at the end user, will tend to be more suitable if using trucks because of the flexibility of transportation.

3.2 Comparison of road and rail reliability levels

3.2.1 Reliability, flexibility, and supply chain visibility

This comparison was assessed from the results of in-depth interviews with goods owners, vehicle owners, and train operators with a triangulation approach. Qualitatively, most stakeholders assessed that road transportation is still more reliable than trains on the Makassar-Parepare route because the mileage factor is only 145 km. If the distance given is more than 200 km, some stakeholders think it might be more reliable to use the train. Some stakeholder opinions from the interview results include:

The Makassar-Parepare route is better to use trucks because the distance is short, the travel time is only 3-4 hours and there is no need for doable handling. Regarding the price, it is predicted that it can still be competitive (although currently there is no certainty about the cost of the train) (Transportation Entrepreneur, 2024).

We want the goods to arrive quickly and be received directly at the warehouse/store; we don't want to be complicated by the long loading and unloading process. The frequency of truck trips to Makassar is also high whenever we need it (Owner of Goods, 2024).

Although, in theory, truck transportation should be inferior to rail transportation in terms of flexibility and dependability. However, in this case, the average value of reliability (reliability, flexibility, and supply chain visibility) of railways is only 2.89 or 58%, while road transportation is 3.19 or 64%. The value of each aspect can be seen in Figure 3.

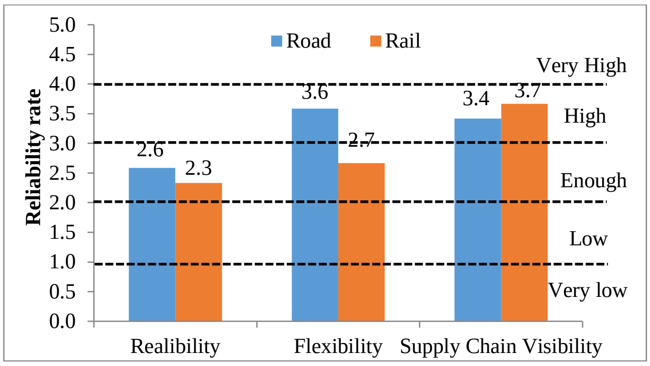

Figure 3. Qualitative comparison of train and truck reliability values

The results of the qualitative analysis (Figure 3) reveal that trains, despite having the potential to be an efficient mode of transportation, are perceived to have lower reliability than trucks. One of the main factors contributing to this perception is the lower frequency of train trips, which only take place 1-2 times per day, compared to trucks, which can operate more flexibly on demand. The longer travel time for trains is also a concern, where a truck trip takes around 3-4 hours, while trains require additional time for the handling process at stations. In addition, trucks offer a door-to-door delivery pattern, making it easy to deliver goods directly to the customer's location without the need for transfers from the station, whereas rail delivery requires a feeder transportation system that adds complexity and delivery time.

This perception has a significant impact on service users' interest in switching to rail, even though rail offers advantages in terms of cost efficiency and reduced carbon emissions, especially for long-distance shipments. The low level of perceived reliability causes rail to be underutilized, potentially reducing its contribution in the overall logistics system. Therefore, to improve the competitiveness of rail, strategic measures such as increasing travel frequency, improving the intermodal logistics system, and developing supporting infrastructure that facilitates more efficient delivery of goods are necessary.

3.2.2 Freight cost

The data shows that vehicles that have a large capacity tend to have a low frequency of travel. This has implications for transportation costs due to limited vehicle capacity. Each vehicle with a different type and configuration of axes will have a different transportation cost, depending on whether it is compared to the distance or compared to the vehicle's carrying capacity. The average transportation cost of road transportation type 1.1 is < 2 million rupiah per trip; for truck types 1.2 and 1.22, it is around 1–3 million rupiah per trip, while for truck type 11.22, the transportation cost is 5–7 million rupiah per trip.

If the benchmark is the transportation cost per distance (IDR/km), the longer the distance, the more expensive the transportation cost. Conversely, if the basis is the transportation cost per capacity (IDR/ton), the higher the vehicle's capacity, the lower the transportation cost. The analysis results in Figure 4 show a comparison of transport costs per km and per ton for vehicles operating in the direction of Makassar to Parepare and vice versa. Vehicle type 1.1 HP has a transportation cost of IDR 4,807/km, while the transportation cost per ton reaches IDR 290,000/ton. The 1.2-22 trailer type vehicle, on the other hand, has a transportation cost of IDR 8,068/km and a transportation cost per ton of only Rp. 62,500/ton. This means that when the goods are being shipped in large quantities, it is more effective to use large vehicles, while when the distance is short, it is more effective to use smaller vehicles.

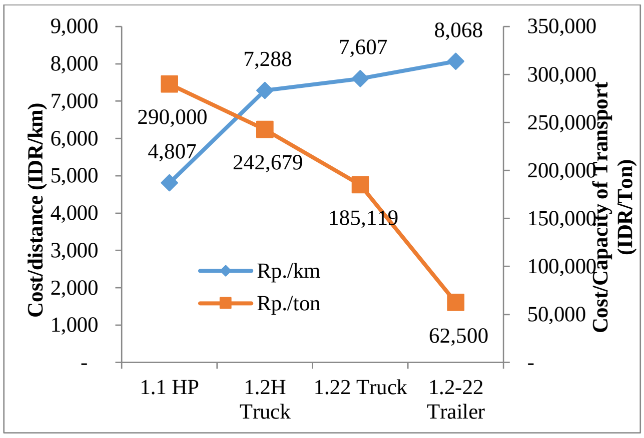

Figure 4. Truck transportation costs based on distance and vehicle capacity

Meanwhile, when compared with the carrying capacity of each type and configuration of vehicles and averaged against the distance traveled by each vehicle (km), the average cost per ton per km is obtained for each type of vehicle. The results of the cost comparison analysis show that the highest is the vehicle type 1.1 HP cost of IDR 573/ton.km, the vehicle type 1.2 H truck cost of IDR 472/ton.km, and the vehicle type 1.22 truck cost of IDR 315/ton.km, while the lowest is the vehicle type 1.2-22 trailer cost of IDR 302/ton.km, with an average of about IDR 404/ton.km.

Of the various commodities transported by trucking with various types and configurations of vehicle axes on the Makassar to Pare-Pare route, the dominant vehicle types are 1.1 HP and 1.2 H trucks. The characteristics of demand that are not too large cause these types of vehicles to be more widely used, even though transportation costs tend to be more expensive. These conditions cause road transportation logistics costs to be uncompetitive and tend to be inefficient. Therefore, the development of rail-based freight transportation is expected to be an alternative to reduce the burden of logistics costs in South Sulawesi.

The cost of truck transportation, when compared to the elasticity of rail transportation costs on both existing routes (commercial routes) in Java, raises several findings. If using the commercial cost set by the Ministry of Transportation in 2022, which is IDR 511/ton.km, the cost is higher than the road transportation cost, which currently averages only IDR 404/ton.km. The difference between the two costs reaches IDR 107/ton.km. However, it should be noted that the assumption for rail costs does not yet accommodate feeder transportation costs (from warehouse to station and vice versa) and handling costs. A comparison of truck transportation costs and rail transportation on the Makassar Parepare route can be seen in Figure 5.

This comparison reflects the trade-off between cost and capacity, where trucks provide greater flexibility in freight delivery with higher frequency and shorter travel times, making them a more economical choice for short-distance and small-volume shipments. In contrast, rail shows advantages in terms of reduced carbon emissions and cost efficiency over longer distances, where the cost per ton can decrease significantly as the volume of cargo increases.

However, in the context of the Makassar-Parepare route, rail tends to be suboptimal compared to trucks, as additional costs related to handling, transfers, and waiting time may offset the cost advantage that rail has. Therefore, it is important to consider these factors in formulating transportation policy and infrastructure development in order to maximize the efficiency and competitiveness of both modes of transportation in the context of goods distribution.

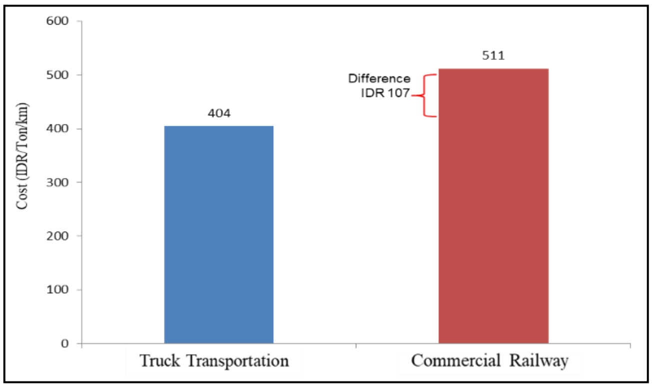

Figure 5. Comparison of truck and train transportation costs on the Makassar

3.2.3 Train operating distance optimization on transportation costs

The use of trains at certain distances is more optimal than trucks. To obtain the optimal distance for using trains, transportation costs were compared with simulated distances. The results of the analysis show that there is an optimal cost at a distance of 360 km. However, if the distance is less than 360 km, truck transportation remains more cost-effective. Therefore, the current Makassar-Parepare train's range of approximately 145 km remains suboptimal in terms of transportation costs. Further simulation of cost comparison based on transportation distance between trucks and trains can be seen in Figure 6.

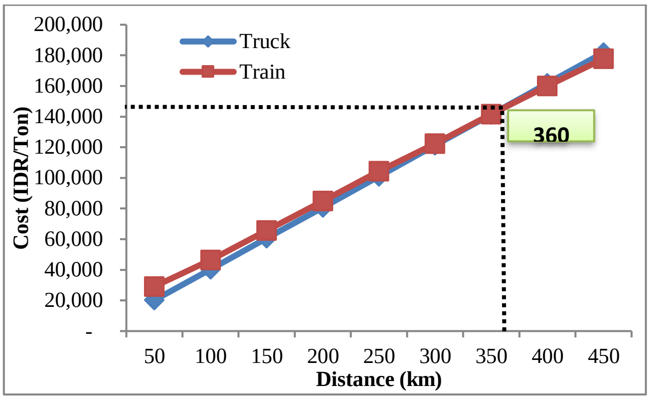

Figure 6. Comparison of optimal cost and distance for truck and rail transportation

In Figure 6, although the optimal point per unit of goods (tons) is at a distance of 360 km, there are other factors that affect the potential for shifting cargo from trucks to trains, namely the demand for cargo. The more cargo that will be transported, the higher the potential for switching, but if the demand for cargo to be transported is still limited, the possibility of switching cargo is relatively low. Therefore, in addition to expanding the service network, the demand for cargo is also very important.

3.2.4 Transportation cost savings

The transfer of cargo from truck transportation to rail will certainly have implications in the form of savings in transportation costs described as opportunity costs for each transfer scenario. In this case, there are four possible scenarios: 70% truck:30 train; 50% truck:50 train; 30% truck:70 train; and 100% train. The calculation of transportation cost savings is seen from the commercial-based rail transportation cost of IDR 511/ton.km and compared to the cost of truck transportation. The analysis shows that there is a significant savings if there is 100% shifting from trucks to trains amounting to IDR 1,755,781/km (if using subsidized costs), but the opposite is a loss if the commercial value is used. This means that under current conditions, the use of commercial costs actually has a loss effect on the total costs incurred by transportation users. Therefore, it is estimated that the implementation of freight train transportation on the Makassar-Parepare route is still difficult to use commercial costs. Details of the estimated cost savings can be seen in Figure 7.

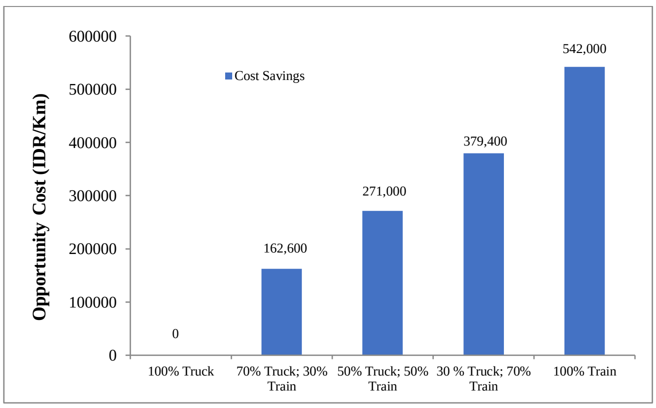

Figure 7. Transportation cost savings due to load shifting (IDR/km)

3.2.5 Fuel saving

Shifting cargo from truck transportation to rail transportation has implications for the savings in fuel used. Assuming the current subsidized fuel price of IDR 6,800 per liter, for the current condition that 100% uses trucks, the fuel consumption cost is IDR 1,542 liters/ton, while if there is a 30% shift to rail transportation, the fuel consumption cost will be Rp. 1,087 liters/ton, or 29.5% lower. Further simulation of fuel savings based on the possibility of shifting cargo can be seen in Figure 8.

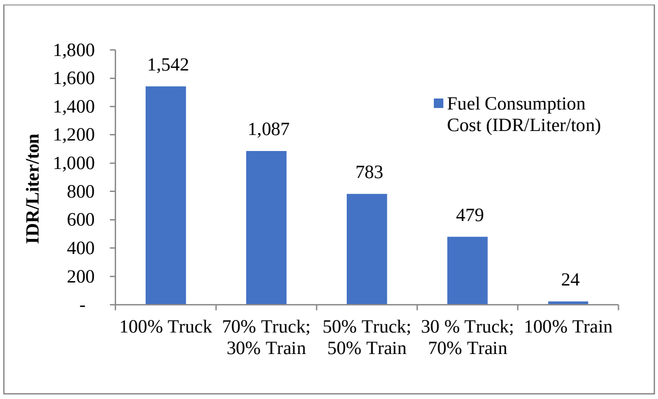

Figure 8. Fuel consumption cost based on load switching

If based on mileage, the savings obtained if there is a switch from truck transportation to rail transportation for each ton of cargo varies greatly; the farther the distance, the greater the cost savings will be. The complete simulation of fuel cost savings for mileage can be seen in Figure 9.

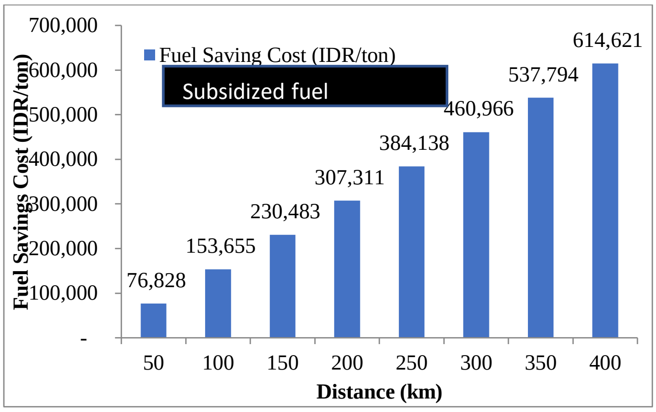

Figure 9. Fuel cost savings by mileage

3.2.6 Carbon emissions

Carbon emissions per ton-kilometer of goods transported by truck and train are very different depending on the type of vehicle. In this study, a comparison of carbon emissions that have been studied in several countries is taken as a baseline. Research [26] in South Africa shows rail carbon emissions of 0.0316 kg/km and trucks of 0.1292 kg/km, while research [27] in California shows truck carbon emissions around 0.0015 kg/km and lower for trains.

Assuming that there are about 358 truck vehicles per day transporting goods from Makassar to Parepare and vice versa with various sizes and capacities, it is estimated that about 98.8 tons per day of carbon emissions are produced. Meanwhile, if a shift of about 30% is made to the train, there is a 22.6% decrease in carbon emissions to 76.4 tons. Details can be seen in Figure 10.

The use of rail not only contributes to the reduction of carbon emissions but also improves energy efficiency in freight transportation. Trains are capable of transporting larger volumes with relatively low fuel consumption per ton-kilometer. This means that by shifting a portion of truck shipments to rail, not only carbon emissions can be reduced, but also the overall use of energy resources. Therefore, the adoption of rail as an alternative mode of transportation can help achieve sustainability goals and reduce the environmental impact of the existing transportation system.

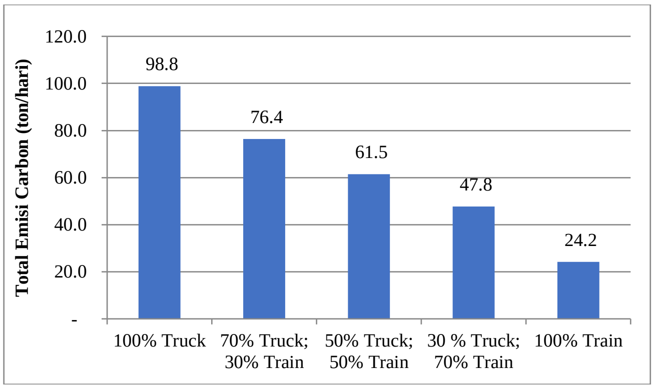

Figure 10. Comparison of carbon emissions in load shifting comparison

3.3 Findings and implications

Assessment of the reliability of rail transportation when compared to truck transportation in the case of the Makassar route towards Parepare is not only in terms of transportation costs but also in aspects of cost savings, reliability, flexibility, supply chain visibility, and carbon emissions. The findings in this study are characterized by a service distance of only 145 km with relatively low potential demand; rail-based transportation tends to be superior in aspects of supply chain visibility, capacity, and transportation cost savings, flexibility, and carbon emissions, while truck transportation tends to be superior in aspects of cost, reliability, travel frequency, and distribution/transportation patterns. The comparison of rail and trucking reliability is described in Table 4.

Table 4. Comparison of the reliability of truck and train transportation on the Makasssa-Parepare route

No.	Characteristics	Truck	Train	Description
1	Reliability	+	O	Train travel time is much faster because it is barrier-free
		++	O	Train frequency is lower because it can only make 1-2 trips a day. Trucks with large numbers have high mobility
2	Flexibility	-	++	The carrying capacity of the train is much larger with a ratio of 1:48 for vehicle type 1.1-22 (trailer). Assuming 1 train consists of 20 cars with a capacity of 75 tons per car
		++	O	The pattern of transportation and distribution of truck transportation is more flexible because it is door to door, as is most of the current transportation demand. Meanwhile,

				trains need onward transportation
3	Supply Chain Visibility	O	+	Train schedules are more regular so tracking of shipment status is more responsive
4	Freight Cost	+	O	Train transportation costs are much lower under the assumption (station to station), but if you include feeder costs and handling costs, truck costs will be much cheaper
5	Freight Cost Savings	-	+	There will be savings if there is a shift of cargo from truck to rail transportation, assuming that rail transportation costs use subsidized costs (due to relatively low cargo characteristics)
6	Fuel Savings	-	++	Fuel savings generated by trains are much lower than trucks
7	Carbon Emissions	-	++	The carbon emissions produced by trains are much lower than trucks

Notes: ++ Excellent, + Good, O Enough, - Poor, -- Very poor

With the travel characteristics of the Makassar-Parepare route, this finding is different from research [14], which shows that on the Makassar-Parepare route it is better to use rail transportation because it is cheaper. Likewise with research [28], which states that rail transportation is better than truck transportation because rail transportation is 13.2% cheaper than truck transportation, even though in the case of short distances it is not optimal.

This study is in line with research [29], which shows that trucking is optimal for short-distance trips. Similarly, the research [30] with a case in Nigeria stated that the comparative advantage of railways is related to capacity and relatively lower freight costs.

The research findings in the form of low reliability of rail transportation on the Makassar-Parepare route, especially on indicators of reliability, flexibility, and transportation costs, indicate that the potential for using trucks as a mode of freight transportation is still high. This has implications for the low interest of service users to use rail transportation. If these conditions persist in the long term, the highway load will increase, and road damage will occur faster than the life of the road. Therefore, to avoid these conditions, short, medium, and long-term policies are needed. In the short and medium term, subsidizing freight loads so that transportation costs are not too expensive can be an option, and service users have a more competitive alternative even far below the cost of truck transportation. Although the consequences will burden state finances. In the long term, the development of rail routes to reach more distant areas (above 500 km) needs to be accelerated to be more competitive with road transportation.

4. CONCLUSIONS

In the context of the Makassar-Parepare route, road transport is qualitatively considered more reliable for relatively short routes, but there is potential for rail to be a better option if the travel distance exceeds 360 km. This finding is based on various factors, including reliability, flexibility, supply chain visibility, and cost aspects. While rail is theoretically expected to be superior in some aspects, the results show that road transport still dominates, especially in terms of cost and frequency of travel.

Currently, road transport is still more competitive than rail from a cost aspect, especially when referring to commercial tariffs. However, there is potential to reduce rail freight costs if subsidized tariffs are implemented. In addition, it is important to consider the environmental impact of both modes of transportation. The use of rail can significantly reduce carbon emissions compared to trucks, which is an important consideration in the context of sustainable development. However, the challenges faced by rail are mainly related to its low reliability and flexibility, which reduces the interest of service users in switching from road transport. To overcome this, efforts need to be made to improve the efficiency and competitiveness of rail, either through subsidies, accelerated infrastructure development, or more favorable network development for users.

In the short and medium term, solutions combining integrated policy and infrastructure approaches can help improve the competitiveness of rail as a more sustainable and efficient mode of transportation. However, these measures must be implemented carefully, considering all aspects involved, including economic, environmental, and social impacts.

This study is limited to the Makassar-Parepare route and may not fully reflect the reliability and cost efficiency of transportation modes on other routes with different characteristics, such as routes with longer or shorter distances, or in areas that have different transportation infrastructure. In addition, the sample size used, although considered representative, still has limitations in terms of the diversity of vehicle types and other variables that may affect the results, such as differences in the types of goods transported and varying road conditions.

Therefore, for future research, it is recommended that a broader study be conducted by covering various routes and vehicle types. The study could expand the scope by analyzing the distribution patterns of goods in other regions in Sulawesi or other regions in Indonesia that have different transportation characteristics. In addition, it can also explore the influence of technology and innovation in the transportation sector, such as the use of environmentally friendly technology or digital-based transportation management systems, which can affect the efficiency and reliability of transportation modes.

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