The Cost Structure of Intermodal Transportation: The Chilean Case

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Abstract**—**This study defines a methodology to compute unitary costs for freight transportation modes. The main objective was to gather relevant costs data to support the formulation and evaluation of railway, road, pipelines and port projects. This article will concentrate on the following steps: Compilation and analysis of relevant modal cost studies, Methodological adjustments to make cost figures comparable between studies, Definition of typology and scope of transportation modes, Analysis and validation of cost values for relevant freight transportation modes in Chile. In order to define the comparison methodology for the costs between the different transportation modes, it was necessary to consider that the relevant cost depends on who performs the comparison. Thus, for the transportation user (e.g. exporter) the pertinent costs are the mode tariffs, whereas from the operators perspective (e.g. rail manager), the pertinent costs are the operating costs of each mode.

Keywords**—**Intermodal costs, Logistics, Transportation costs.

I. Introduction

THE information about freight transportation cost has been widely studied for the road mode and the values of all it components [1]-[4].

Nevertheless, for other modes, like rail, maritime and pipelines, the information about their operation cost is not readily available at the same level of detail [5]-[9], precluding direct comparisons among the cost structures of all the available modes for a given project.

Having a cost structure comparable between modes allows the analysis of the benefits of using each available mode within different operations scenarios (volume of freight to be transported, distance, type of commodity, etc.), serving as an aid to the decisions making process in the public sector regarding investment in dedicated infrastructure (e.g. sea ports, rail roads).

A. Objectives

The general objective of this study, commissioned by the Chilean Ministry of Transportation [10], was twofold. First: defining a methodology to compute unitary costs for freight transportation modes. Second: finding a set of values for the most used modes of freight transportation in Chile. The ultimate aim was to gather relevant costs data to support the formulation and evaluation of railway, road connection, pipelines and sea port projects.

Among the various tasks carried out in the original study, this article will concentrate on the following steps:

- Compilation and analysis of relevant modal cost studies
- Methodological adjustments to make cost figures comparable between studies
- Definition of typology and scope of transportation modes
- Analysis and validation of cost values for relevant freight transportation modes in Chile.

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II. Methodological Adjustments to Make Cost Figures Comparable between Studies

In order to define the comparison methodology for the costs between the different transportation modes, it was necessary to consider that the relevant cost depends on who performs the comparison. Thus, for the transportation user (e.g. exporter) the pertinent costs are the mode tariffs, whereas from the operator perspective (e.g. rail manager), the pertinent costs are the operating costs of each mode.

Considering above described objectives, the authors proposed a cost structure from the perspective of the transportation operator, which allows and objective comparison of each transportation mode leaving out the distortions that market imperfections may introduce in the structure of freight rates.

To define the proposed structure it was necessary to analyze each item and components of the operation cost for each mode and determining the possible correspondence among them to allow a fair caparison between the different modes. In addition the availability of information was taken into considerations when defining the cost structure. Primary and secondary sources were consulted aider from the operator themselves or the appropriate literature.

Given the fact that each mode has particular operation characteristics not all the components can be clearly isolated. Therefore all those items were added together within the category of *other operational expenses*.

Freight handling cost was not included in the operational cost because this item is usually paid by the shipper and not by the transportation operator.

The proposed cost structure considered the following items:

- Power consumption
- Circulation cost
    - Vehicle insurance
    - Rights of way
- Maintenance
- Personnel
- Capital cost
- Managerial cost
- Other operational expenses

III. Definition of Typology and Scope of Transportation Modes

There are many factors that can influence the operational cost components defined in the previous section, especially if we consider the characteristics of each mode. However, beyond the peculiarities, the authors were interested in defining common elements that delimit the operation of each of them and to define appropriate aggregation level for comparison.

Moreover, the higher the level of disaggregation, most requests for information, which implies high costs of gathering information, difficulty in updating and loss of confidence by the greater likelihood of error in data collection. All this without considering the willingness of companies to provide information, which is generally low given the economic implications they believe may have delivered the requested data.

Thus, for the definition of the types of costs in this study, it was considered a level of aggregation that would allow representatively capture major freight movements in Chile, taking into account the information available and ease of upgrade.

A first level of aggregation has to do with the loads to be transported. For this we considered the following types:

- Break bulk
- Reefer
- Liquid Bulk
- Bulk

With this aggregation, the main products transported in Chile can be associated to any of these categories, thereby facilitating comparisons between modes.

Moreover, it was necessary to define a zoning to represent the main features of the operating costs associated with the movement of cargo in the country. For this we used zoning studies conducted in other cargo movement in Chile and these are: North, Central and South. Within each zone, longitudinal and transverse movements considered.

Only long distance maritime movements were incorporated into the analysis, because this mode is not significant in shorter distance trips.

Having defined the product categories and zones of analysis, we proceeded to determine a representative vehicle per mode, which fulfilled the necessary conditions to carry these types of freight and the restrictions of each zone.

A. The Representative Vehicle for Rail

To define a representative vehicle for rail, i.e. a train that adequately represents the railroads that operate today in Chile; we analyzed the characteristics of the railways in the different zones of the country. Significant differences were observed between the vehicles operating in the northern zone and the other zones.

Within the definitions made are the type of car to tow, and the towing capacity of the locomotives. The towing capacity is defined by gradient (slope of the land), curvature and weight of the freight, and thus it varies according to the zone where the railroad runs. According to the towing guidelines provided by the railway operating companies in Chile, it is possible to associate an average towing capacity for the locomotives of each zone, as outlined below:

- North Zone. HP 1400 Diesel Locomotive with average towing capacity 600 t (load + tare).
- South Central Zone. HP 2300 Diesel Locomotive with average towing capacity 1200 t (load + tare)

As for the type of car to consider, we have defined the following car models based on the type of load to be transported. Is noted that in the case of bulk tanks, they had to be disaggregated by zone, since there are tanks of different capacities and hence of different weight. The tare and load defines the axle weight determined and therefore the type of road which can circulate. In Table I is shown the characteristics of the used car.

TABLE I
Car Types

Freight	Car type	Tare	Load capacity (t)
Break Bulk	Flat Car	12	30
Reefer	Reefer Car	15	30
Bulk	Bulk Tank South	22	50
	Bulk Tank North	18	30
Liquid Bulk	Liquid Bulk Tank South	28	70
	Liquid Bulk Tank North	20	40

Finally, considering locomotive type, towing capacity and type of car, we determined the load capacity for each representative trains, which are shown in Table II.

TABLE II
Representative Vehicle for Rail

Train type	Towing capacity (t)	Car type	Load capacity (t)
HP 1400 Locomotive	600	Flat Car	420
		Bulk Tank North	360
		Liquid Bulk Tank North	400
HP 2300 Locomotive	1,200	Flat Car	840
		Reefer Car	780
		Bulk Tank South	800
		Liquid Bulk Tank South	840

B. The Representative Vehicle for Maritime Mode

To define representative vehicle for maritime mode we selected specialized ships. The selected vessels were the following:

- Break bulk and reefer: multipurpose (MPP) ship, 8,000 DWT, year 2000
- Bulk: Bulk ship, 27,287 DWT, year 1998
- Liquid bulk: Tanker IMO 2-3, 25,148 DWT, year 2003

C. The Representative Vehicle for Roads

In the case of road transport, we used the standard set up by [2], which defines various truck configurations. Considering the objectives of this study we chose large trucks with high capacity, since the comparison between ships, trains, trucks and pipelines only makes sense with large volumes of cargo.

Thus, the representative vehicle for roads is shown in Table III.

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TABLE III
TRUCK TYPES

Freight	Truck type	Load capacity (t)
Break Bulk	Flat trailer	25
Reefer	Reefer trailer	25
Bulk	Dump truck	25
Liquid Bulk	Tanker truck	25

D. Representative Pipelines

Pipelines move solid bulk cargo and liquid. According to information collected, the bulk solids are transported by pipeline mainly for mining products.

Slurry pipeline was defined from 6-9 inches in diameter as a proxy for transport of copper concentrate in the north, while for liquid bulk products the defined pipeline was 8 and 10 inches in diameter.

IV. Analysis And Validation Of Cost Values For Relevant Freight Transportation Modes In Chile

A. Operational Cost for Rail

Tables IV and V show the operating costs for railway.

TABLE IV
OPERATING UNIT COST NORTHERN RAILWAY (USD/T-KM)

Cost Item	Northern railway USD/t-km		
	Locomotive 1400 HP flat car	Locomotive 1400 HP Bulk Tank North	Locomotive 1400 HP Liquid Bulk Tank North
Power consumption	0.01	0.01	0.01
Circulation cost	0.00004	0.00004	0.00004
Maintenance	0.01	0.01	0.00
Personnel	0.002	0.002	0.002
Capital cost	0.01	0.01	0.01
Managerial cost	0.001	0.001	0.001
Other operational expenses	0.001	0.001	0.001
Total	0.03	0.03	0.03

TABLE V
OPERATING UNIT COST SOUTH CENTRAL RAILWAY (USD/T-KM)

Cost item	South central railway USD/t-km			
	Locomotive 2300 HP flat car	Locomotive 2300 HP Reefer Car	Locomotive 2300 HP Bulk Tank South	Locomotive 2300 HP Liquid Bulk Tank South
Power consumption	0.01	0.01	0.01	0.01
Circulation cost	0.002	0.002	0.002	0.002
Maintenance	0.004	0.004	0.004	0.003
Personnel	0.001	0.001	0.001	0.001
Capital cost	0.01	0.02	0.01	0.01
Managerial cost	0.001	0.001	0.001	0.001
Other operational expenses	0.001	0.001	0.001	0.001
Total	0.03	0.03	0.02	0.02

Based on these results it is possible to obtain the composition of costs for each railway as shown in Tables VI and VII.

TABLE VI
COMPOSITION OF OPERATIONAL UNIT COST FOR NORTHERN RAILWAY

Cost Item	Northern railway		
	Locomotive 1400 HP flat car	Locomotive 1400 HP Bulk Tank North	Locomotive 1400 HP Liquid Bulk Tank North
Power consumption	41.3%	40.7%	41.9%
Circulation cost	0.2%	0.1%	0.2%
Maintenance	17.8%	16.7%	16.8%
Personnel	6.7%	6.6%	6.8%
Capital cost	27.8%	29.7%	28.2%
Managerial cost	3.3%	3.2%	3.3%
Other operational expenses	2.9%	2.9%	2.9%
Total	100%	100%	100%

TABLE VII
COMPOSITION OF OPERATIONAL UNIT COST FOR SOUTH CENTRAL RAILWAY

Cost Item	South central railway			
	Locomotive 2300 HP flat car	Locomotive 2300 HP Reefer Car	Locomotive 2300 HP Bulk Tank South	Locomotive 2300 HP Liquid BulkTank South
Power consumption	26.8%	26.1%	34.5%	35.1%
Circulation cost	6.7%	6.1%	8.2%	8.8%
Maintenance	12.6%	11.9%	14.1%	13.8%
Personnel	3.1%	3.0%	4.0%	4.1%
Capital cost	45.8%	47.9%	33.6%	32.6%
Managerial cost	2.1%	2.1%	2.6%	2.6%
Other operational expenses	2.9%	2.9%	2.9%	2.9%
Total	100%	100%	100%	100%

B. Operational Cost for Trucks

Table VIII presents the consolidated results of marginal costs by truck operation.

TABLE VIII
OPERATING UNIT COST FOR TRUCKS (USD/T-KM)

Cost Item	Unitary operational cost of trucks USD/t-km			
	Flat trailer	Reefer trailer	Dump truck	Tanker truck
Power consumption	0.02	0.02	0.02	0.02
Circulation cost	0.002	0.002	0.002	0.002
Maintenance	0.005	0.01	0.01	0.01
Personnel	0.01	0.01	0.01	0.01
Capital cost	0.003	0.004	0.003	0.004
Managerial cost	0.002	0.002	0.002	0.002
Other operational expenses	0.001	0.001	0.001	0.001
Total	0.037	0.040	0.042	0.039

Based on these results it is possible to obtain the composition of costs for each truck as shown in Table IX.

TABLE IX
COMPOSITION OF OPERATIONAL UNIT COST FOR TRUCK

Cost Item	Flat trailer	Reefer trailer	Dump truck	Tanker truck
Power consumption	46.2%	43.6%	47.1%	44.5%
Circulation cost	5.1%	4.7%	4.6%	4.8%
Maintenance	13.5%	14.8%	15.1%	14.4%
Personnel	19.2%	17.8%	17.0%	18.1%
Capital cost	7.0%	10.8%	8.2%	9.7%
Managerial cost	5.4%	4.9%	4.7%	5.0%
Other operational expenses	3.6%	3.3%	3.2%	3.4%
Total	100%	100%	100%	100%

From table above we can see that again fuel is the heaviest item in the composition of costs, followed by salaries and maintenance.

C. Operational Cost for Ships

Table X presents the consolidated results of marginal costs per ships operation.

Based on these results it is possible to obtain the composition of costs for each ship as shown in Table XI.

TABLE X
OPERATING UNIT COST FOR SHIPS (USD/T-KM)

Cost Item	Unitary operational cost of ships (USD/t-km)				
	Bulk ship direction Center to North	MPP ship direction Center to South	MPP ship direction South to North	Bulk ship direction North to South	Tanker direction Center to North
Power consumption	0.003	0.004	0.002	0.001	0.002
Circulation cost	0.0004	0.0008	0.0002	0.0002	0.0002
Maintenance	0.001	0.001	0.000	0.001	0.001
Personnel	0.002	0.003	0.001	0.000	0.001
Capital cost	0.0004	0.0008	0.0002	0.0004	0.0006
Managerial cost	0.0004	0.0006	0.0002	0.0001	0.0001
Other operational expenses	0.0002	0.0006	0.0002	0.0002	0.0002
Total	0.006	0.011	0.005	0.003	0.004

TABLE XI
COMPOSITION OF OPERATIONAL UNIT COST FOR SHIPS

Cost Item	Bulk ship direction Center to North	MPP ship direction Center to South	MPP ship direction South to North	Bulk ship direction North to South	Tanker direction Center to North
Power consumption	43.5%	34.0%	49.8%	43.5%	43.4%
Circulation cost	7.0%	8.1%	6.2%	5.5%	5.6%
Maintenance	10.4%	12.1%	9.2%	20.1%	19.4%
Personnel	25.0%	29.1%	22.1%	14.2%	12.0%
Capital cost	5.5%	6.5%	4.9%	9.8%	13.6%
Managerial cost	4.7%	5.5%	4.1%	2.2%	2.2%
Other operational expenses	4.0%	4.7%	3.8%	4.7%	3.8%
Total	100%	100%	100%	100%	100%

The newly obtained costs are not comparable directly with the operating costs of the other analyzed modes, because the use of ships involves an additional cost associated with the approach from the origin of the load and delivery to the final destination. These movements from / to port can be made in any of the 3 modes.

D. Operational Cost for Pipeline

Table XII presents the marginal costs of operation for pipelines.

Based on these results it is possible to obtain the composition of costs for each pipeline. The results are presented in Table XIII.

TABLE XII
OPERATING UNIT COST FOR PIPELINE (USD/T-KM)

Cost Item	North Pipeline 9 inches transverse movement	Center Pipeline 8 inches longitudinal movement	Center Pipeline 10 inches transversal movement
Power consumption	0.004	0.001	0.000
Circulation cost	0.0035	0.0004	0.0002
Maintenance	0.003	0.001	0.0004
Personnel	0.007	0.002	0.001
Capital cost	0.005	0.002	0.001
Managerial cost	0.001	0.003	0.001
Other operational expenses	-	-	-
Total	0.024	0.009	0.003

TABLE XIII
COMPOSITION OF OPERATIONAL UNIT COST FOR PIPELINE (%)

Cost Item	North Pipeline 9 inches transverse movement	Center Pipeline 8 inches longitudinal movement	Center Pipeline 10 inches transversal movement
Power consumption	16.8%	11.6%	8.8%
Circulation cost	15.0%	4.6%	4.3%
Maintenance	13.3%	9.7%	9.5%
Personnel	28.85	19.6%	20.5%
Capital cost	21.2%	23.6%	26.8%
Managerial cost	5.0%	30.9%	30.2%
Other operational expenses	-	-	-
Total	100%	100%	100%

E. Competitiveness Analysis

The analysis of competition between modes, for different zones and types of products, was carried out considering the following approaches:

- Marginal costs of operation
- Fixed and variable costs of operation

Marginal cost allows finding the most efficient mode for additional T-km, while the fixed and variable costs of operation determine the mode with lower operating costs for different load volumes.

The presented results correspond to the estimates for each vehicle type operating at full capacity. This latter assumption was made only as a comparative tool because occupancy rates of each mode vary according to the operation. Thus, for analysis of individual cases of operation, it is recommended to consider the specific occupancy rates according to the expected capacity utilization in return trips.

1. Marginal Costs of Operation

The marginal cost of operation shows the dominance of the pipeline over the railway and the truck. The cost of the pipeline is 0.02 USD/t-km, while the railway reaches 0.03USD/t-km and the truck exceeds 0.03USD/t-km.

Regarding the cost structure of each mode, we see that only in the pipeline case the most important component is salaries rather than fuel.

2. Fixed and Variable Operating Costs

As stated above, the marginal costs include both fixed and variable costs of operation. However, to determine the volume of cargo that makes each mode competitive, it is necessary to breakdown these operating cost.

Cost items considered fixed (not dependent on the use of the vehicle), are the following:

- Circulation cost
- Salaries
- Capital cost
- Managerial cost
- Fixed cost of maintenance

The rest of the items such as fuel, variable maintenance and other operating costs were considered dependent on vehicle use.

The fixed operating costs for the northern zone are 36,415 USD/year in the case of truck, 2,453,872 USD/year for the pipeline and 156,623 USD/year for the railway. Note that the fixed cost for the pipeline is more than 16 times the annual fixed cost for the railway.

However, when analyzing the variable operating costs for the same zone, the truck present the higher cost per t-km, reaching 0.03 USD/t-km versus the 0.01USD/t-km for the pipeline, or the 0.02USD/t-km for the railway.

From the above information, it was possible to design graphics as presented in Fig. 1 in which one could determine the most convenient mode according to the t-km transported for a year. The intersection on the Y axis corresponds to fixed costs, while the slope of the line shows the variable costs of each mode.

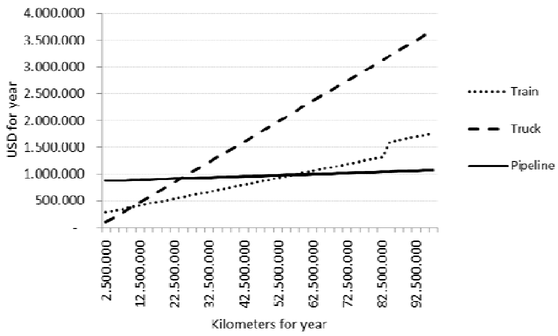

Fig. 1 Total Cost of Operation of Bulk Liquid Transport in the Northern Zone

Fig. 1 shows the low fixed costs of truck and rail over the pipeline, while the steepest slope corresponds to the truck, which makes it a convenient mode to transport low cargo volumes (up to 7,500,000 t-km per year). Past this point, the railway emerges as the most convenient mode up to 130,000,000 t-km, from which the pipelines becomes the best alternative.

V. CONCLUSION

The results show that regardless of the type of load and geographical zone the unit operating cost per T-km of transport modes can be ordered from lowest to highest, as follows: pipeline, marine, rail, road.

The results show a clear need to strengthen the railways in terms of transverse movements, which is not to compete directly with the truck, but should aim to enhance intermodality in search of the use of the advantages of each mode.

As for longitudinal movements, the maritime mode presented the lowest operating costs.

We conducted an analysis of fixed and variable costs of operation, which allowed determining what is the volume of cargo that require different modes to be competitive. It was concluded, according to the conditions studied, the truck is the most suitable for quantities smaller than 7,500,000 t-km per year, then followed by railroad. Moreover, both the pipeline and shipping mode are attractive alternatives for quantities greater than 100,000,000 t-km per year, due to their high fixed operating costs.

According to these results, intermodal transport is presented as an attractive alternative that would make use of modes in their areas of highest efficiency. So the truck with short journeys could feed both rail and shipping mode, so that they have the necessary cargo volume to justify its operation.

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