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Cost Models and Cost Factors of Road Freight Transportation: A Literature Review and Model Structure

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ABSTRACT

This paper presents a detailed comparative review of cost models and cost factors published in a number of studies on freight transportation. It attempts to determine and categorise cost factors from a different point of views in the reviewed studies which include cost factors (operational costs, value of time and external costs), study area (Europe, the United States, North America and Asia) and cost models (activity-based costing (ABC), statistical models, surveys, data mining, GIS, meta-analysis and Mathematical models). The results are assessed by comparison with the reviewed studies. The paper also proposed two model structures; (1) Road freight transportation costs (2) Road freight transportation cost estimating methods and data gathering. These models are designed to identify any gaps between the types of cost or any inconsistencies in cost factors and consist of an overall structure and multiple substructures.

KEYWORDS

Cost factors; cost models; fuzzy programming; model structure; operational costs; road freight transportation costs

1. Introduction

Because of globalisation and a longer and more complex supply chain, logistics plays a more critical role in developing a successful supply chain. Freight transportation cost has become one of the most important economic indicators of supply chain efficiency [1]. Several previous studies have investigated various types of transportation costs. From past studies, three perspectives for classification of freight transport costs can be considered; (1) From the freight transport operators' Perspective, freight transport costs refer to the expenditure they incur in providing the services. These costs refer to operational costs. (2) From the freight owners' Perspective, freight transport costs refer mainly to the prices or charges they pay to freight transport operators. Some Freight owners tend to pay more for faster and more reliable shipping. These preferences create the value of time costs for freight transportation. And (3) From the national perspective, freight transport costs include costs associated with social, environmental and economic aspects, which include financial, non-financial, tangible and intangible components. These costs refer to external costs [2].

Over the years, researchers have studied a wide range of cost factors and used a broad scope of methodologies to estimate freight transportation costs. Different types of studies have different purposes, which affects their perspective, methodologies and scope. In this

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paper, for comparing cost studies the following factors considered; (1) The purpose of the analysis, and therefore its perspectives, such as whether it considers only short-run costs or total costs. (2) Categories of impacts considered, including vehicle costs, travel time costs, parking costs, accident costs, pollution emissions and other impacts. (3) Data sources and methodologies used to calculate costs. (4) Geographic scope and time period evaluated. And, (5) The types of freight transportation (including Truck, Rail, air, and marine vehicles).

By analysing the state of art of freight transportation costs estimation in recent years, the lack of papers which cover all types of freight transportation costs, as well as all kinds of methods for estimating them, and for a variety of transportation modes, has become apparent. This paper investigates, gathers and summarises the evolution of research and current thinking as it relates to freight transportation cost estimating factors and methods for the road, rail, air, and waterways freight transportation modes and covering the studies in the United States, Europe, North America, South America, and Asia.

2. Review of the Literature

A review of past experiences and previous studies has shown that there is a great deal of scope and scope both in terms of time scale and in terms of the number of studies. To obtain the optimal results of the studies, classification concerning the subject of previous studies has been presented as follows:

- Operational costs and freight transportation cost functions
- Value of time
- External costs

In this section we investigate the state of the practice for freight cost estimation for all above three groups.

2.1. Operational Costs and Freight Transportation Cost Functions

Operational costs are those expenses incurred in the daily running of a business and are internal to the carriers and include both fixed and variable costs [3]. Fixed costs are defined as the costs of having a vehicle standing and available for work, and are not subject to frequent change and are not generally affected by the amount that the vehicle is used. Examples of fixed costs include vehicle excise duty, vehicle insurance, operator's license fee, drivers' guaranteed wages, depreciation, and overheads. Variable costs are factors which their level depends on the actual use of the vehicle. The costs of fuel, lubricants, tires and repairs and maintenance are examples of running or variable vehicle operating costs [4].

Three areas of innovation in freight transport modelling can be summarised as follows:

- Freight–economy linkages,
- Logistics behaviour, and
- Freight trips and networks.

Modelling the transport of goods requires (1) further details (vehicle types, logistics, spatial characteristics), and (2) an expansion of dimensions of the freight transport model to a

wider transportation system (geographically, as well as operationally and economically) [5]. In order to freight transportation modelling be meaningful, this modelling should be done at the appropriate level of detail, data disaggregation and analysis of data. The accuracy and availability of data for freight transportation modelling are equally important [6–9].

Brinckerhoff [10] presented a review of freight modelling. This study examines the existing models of freight transportation and assesses the appropriateness of available potential options, have recommended the most appropriate methods for use in the UK. From the study, modelling in the field of road freight transportation, especially pricing should include commodity types, shipping policy, service delivery characteristics, vehicle characteristics and model horizons.

Kordnejad [11] investigated the intermodal transport cost model and intermodal distribution in the urban environment in Europe. The study aims to model a regional rail-based intermodal transport system for a shipper of daily consumables distributing in an urban area and to evaluate it regarding cost and emissions. findings shows that the total transport cost for a combined transport chain are consist from the total cost generated by the main haul i.e. rail operations, the total cost for road haulage consisting of pre- and post-haulage to terminals and total cost for terminal handling, which is derived from the cost per transferred unit associated with the type of terminal.

Kulović [12] studied freight transport cost model based on truck fleet operational parameters. To investigate the main factors that may affect freight transport costs it is useful to examine the influence of trucks fleet operational parameters on transport costs. The freight cost model presented in Kulović is based on the operational parameters of the truck fleet. These parameters are various coefficients that indicate the amount of fleet use, time, truck capacity and path (route), average speed, and distance of loaded truck travelled.

Radhakrishnan and Anukokila [13] studied a solid transportation problem with interval cost using fractional goal programming approach (FGP). The purpose of developing the fuzzy goal programming model was the decision-maker(s) difficulties to determine the goal value of each objective precisely as the goal values are imprecise, vague, or uncertain. Also, they use a special type of non-linear (hyperbolic) membership function to solve the multi-objective transportation problem. It gives an optimal compromise solution.

Musso [14] compared the freight transportation costs in Europe through a survey known as (SOFTICE¹). In the research, a method for cost estimation was developed using four main approaches: (i) market segmentation; (ii) integration of transport in the logistics chain; (iii) quality of services, and (iv) external costs and means of internalising. The results revealed that drivers' wages for truck collection and distribution of goods were heavily influenced by other factors (50.4 percent). Three smaller cost factors similar in magnitude are administration (11.6 percent), depreciation (10.9 percent), and fuel (10.3 percent). The analysis of taxes refers to two different categories: direct and indirect. Results indicated that direct taxation on truck operations amounts to a small percentage of the total costs, which varied among countries.

Zofio et al. [15] examined the general costs of freight transportation through a geographical analysis of economic and infrastructure fundamentals. As a Value Index, generalised transport costs (GTCs) can be divided into price and quantity indices for the economic – market – costs and infrastructure variables – distance and time within a network. In Zofio's

¹ Survey on Freight Transport Including a Cost Comparison for Europe.

article, road freight transportation in Spain between 1980 and 2007 has been surveyed at a very precise geographic level. The average GTCs weighted by trade flows have decreased by 16.3%, with infrastructure driving that reduction.

Janic [16] developed a model for calculating comparable combined internal and external costs of intermodal and road freight transport networks. The study indicates that internal costs are the cost of each component of the transportation function includes the cost of ownership, insurance, repair, maintenance, labour, fuel, taxes, and tolls paid for using the network. The external costs include the costs of the impacts of both networks on society and the environment such as local and global air pollution, congestion, noise pollution, and traffic accidents. This model applies to the simple configuration of both networks using the inputs from the European freight transport system.

Levinson et al. [17] investigated the operating costs for trucks. A survey of firms that undertake commercial truck road movements was performed. The average operating cost per kilometre for commercial vehicle operators was calculated from the survey responses. Results show that the trans-log and Cobb–Douglas models have approximately equal explanatory power in estimating the total cost from the data. The models also revealed the presence of nearly constant returns to scale, a finding consistent with earlier studies; an increase in output (total truckloads) of 1% increases total costs by 1.04%.

Trego and Murray [18] studied trucking operating costs. In this research, they used a survey to receive the required information. Survey questions targeted average aggregate carrier cost per mile or cost per hour for 2008. Marginal costs are generally divided into two groups, vehicle and driver-based as follows:

- Vehicle-based cost factors: (1) Fuel and Engine Oil; (2) Truck/Trailer Lease or Purchase Payments; (3) Repair and Maintenance; (4) Fuel Taxes; (5) Truck Insurance Premiums; (6) Tires; (7) Licensing and Permits; (8) Tolls and;
- Driver-based cost factors: (1) Driver Wages; (2) Driver Benefits and (3) Driver Bonuses.

The survey findings indicate that the average marginal cost per mile (CPM) is \$1.73 and the average cost per hour (CPH) is \$83.68. The highest costs were for diesel/oil, driver's wages and truck/trailer rentals or purchases.

Holguín-Veras & Brom [19] studied Trucking costs in metropolitan areas. They discussed the results of a comparative analysis of two methods of estimating cost models: econometric estimation and cost accounting. The analysis indicated that in cases where it is possible to gather a large quantity of quality data on costs or where precise estimates are required, econometric modelling is undoubtedly the best option. In other circumstances, especially in cases where costs are low, the cost-accounting approach is also appropriate. The estimation process was linear and Cobb–Douglas models. Various independent variables, in addition to time, distance, and number of stops were included in the regressions (including commodity type, fleet ownership, distance to the first stop, and number of employees).

Lindsey et al. [20] investigated Modelling freight rates for trucks in spot markets using North American data mining and GIS. The research has found that factors such as distance, characteristics of the shipping lane and the required truck type are among the most important determinants of motor carrier rates at both the shipment and lane level. Also, seasonality and overall market conditions play a major role in determining rates for truckload

shipments. The data for their study comes from a U.S.-based 3PL provider operating in North America.

Qiao et al. [21] investigated a decision-making problem consisting of less-than-truckload dynamic pricing (LTLDP) under the Physical Internet (PI). PI can be seen as the interconnection of logistics networks via open PI-hubs, which can be considered as spot freight markets where LTL requests of different volume/destination continuously arrive over time for a shortstop. Carriers can bid for the requests by using a short-term contract. The results showed that the proposed model could optimise the carrier's bid price to maximise the expected profits and three influencing factors were investigated: requests quantity, carrier's capacity, and cost.

Zhang et al. [22] presented an optimisation of freight truck driver scheduling based on operation cost Model for Less-than-Truckload (LTL) transportation. They introduced the new Time-Driven Activity-Based Costing (TDABC) method, TDABC-FTC for truck freight companies. Also, an artificial neural network (ANN) model is introduced to capture the relations between driving behaviour and fuel consumption rate. The results showed that the newly introduced methods presented considerable benefit of the optimal scheduling techniques.

Conrad and Joseph [23] studied costs and challenges of log truck transportation. This study involved interviews with 18 log truck owners operating in the state of Georgia, USA. The results showed that the most important challenges were a shortage of qualified drivers and rising truck insurance premiums. Increasing percent-loaded km, reducing turn times at mills and harvest sites, providing driver training, and adopting technologies, such as global positioning system tracking and on board cameras, could improve transportation efficiency and safety.

Hooper and Murray [24] presented An Analysis of the Operational Costs of Trucking. They studied the American Transportation Research Institute's (ATRI's) annual motor carrier operations costs report. Average marginal costs were based on vehicle costs (fuel, insurance, permits, tolls, repair, and lease or purchase payments) and driver costs (wages, benefits). The average carrier cost per mile in 2017 was \$1.691, an approximately 6 percent increase from 2016 costs. The average carrier cost per hour was \$66.65 versus \$63.66 in 2016. Driver wages and benefits represent 43% of total average marginal costs and fuel costs represent 22%.

2.2. Value of Time (VOT)

Accent and Hague Consulting Group [25] investigated the value of travel time on UK roads. They used a survey to describe the preferences and the conditional logit model. Also, in designing the test, the preferences of time and cost variables expressed with 3 feature levels and in 10 pairs of selection groups based on a full factorial method. They examined the variety of goods and the level of road density. The results of the research have shown that reliability is significant in the road transport industry and a 1% increase in the probability of delay of 30 or more min. is equivalent to 0.45–1.8 Euro per transport.

Kawamura [26] studied the value of time for truck operators in California. He surveyed truckers about choosing between a free road against a road with tolls, but with different cost and travel time. The estimation was based on the shift point of the facility levels at questions and also used a modified logit model, which assumed that the estimated coefficients

had a log-normal distribution in the sample population. The results of the comparison between the data set which were segmented according to business type, size of the shipment and the way of payment to the driver indicated that for-hire trucks tend to have higher values of time than private ones and the companies that pay drivers hourly wages have higher values of time than those who pay commissions or fixed salary.

Kurri et al. [27] conducted two separate studies using the same method to estimate the value of time for road and rail freight transportation in Finland. In this study, the 'stated preferences' method was used, in which hypothetical choice situations between road or rail transport alternatives were presented. According to the survey, the average value of time for road transport for the selected commodity groups is about \$1.5 per metric ton per hour, and the value of average delay is about \$47 per metric ton per hour. For rail transport and different commodity groups, the average value of transport time is about \$0.10, and the value of the average delay is about \$0.5 per metric ton per hour

Bruzelius [28] studied the valuation of logistics improvements in cost-benefit analyses (CBA) of transport investments through a survey. According to the results of the study, the value of the risk of delay is 6.1 Euro per mile for road transport, 111.3 Euros for rail transport and 25.7 Euros for air transport. This study was based on the 'Stated Preference' survey from Swedish transport companies in 1999, and the attributes included costs, transport time and the probability of delay.

Bolis and Maggi [29] examined the choices of road freight transportation services by adaptive stated preference experiments in Italy and Switzerland. In designing the survey the variables were price, time, reliability, mode, frequency and flexibility. The statistical population consisted of 24 shipping companies and also, a Tobit linear model was used to analyze the data. The results of the research have shown that the values of time and characteristics (reliability, frequency, etc.) provide important insights and permit generalised costs in freight transport models to be recalibrated.

Fowkes et al. [30] investigated the user valuations of three types of delay included (1) A delay resulting from an increased travel time, with fixed departure time; (2) An increase in the range of arrival time for a fixed departure time; (3) A scheduled delay where the departure time is effectively backed up. To assess any delay, they used a 'stated preference' survey in England and the variables included: time, costs, late departure time, earliest delivery time and delivery time. The authors stated that a high level of reliability and reliability of travel time is necessary for effective performance. Reasons for such necessity are (1) demand considerations (timely and prompt delivery strategies, port deadlines, hub & spoke operations), and (2) supply issues (double-sided loading; delivery insurance; driving times scheduling; 24 hours operation planning; management and storage instructions).

Danielis et al. [31] studied logistics managers' preferences for freight service attributes in n two Italian regions and used an adaptive conjoint analysis (ACA) experiment. The attributes of their study were costs, travel time, Punctuality and Damage and loss. The experiments consisted of four sets of questions: (1) unacceptable levels; (2) the importance of attribute levels; (3) paired-comparison trade-offs, and (4) calibration. A great deal of preference was given to features related to cost, especially for reliability and safety. However, these preferences are not easily met by increasing road congestion and inefficient multimodal transport systems in Italy.

Zamparini and Reggiani [32] investigated the Value of Freight Travel Time Savings (VFTTS) through a meta-analysis of empirical studies in several European and North

American countries. By examining the descriptive statistics, it was possible to ascertain that the average VFTTS for road haulage is remarkably higher than the average VFTTS in rail transport. Moreover, in contrast to a previous estimation conducted on the VTTS for passenger transport, most of the proposed explanatory variables (the dummy variable for the Northern European Region, the dummy variable for rail transport, and the natural logarithm of per-capita GDP) have statistically significant coefficients.

Massiani [33] studied the use of hedonic pricing to estimate freight value of time, where transportation time is defined as travel time plus the time necessary for all other logistical operations between the loading of the goods at origin and the unloading at destination. He pointed out that freight transportation services are different from other goods usually analysed through hedonic pricing. In Mason's research the hedonic pricing method was customised to calculate the freight value of time. For this purpose, a fitted linear model was presented based on the data collected from interviewing companies in which time and speed variables were determined as price characteristics.

Dejong et al. [34] investigated the values of time and reliability for freight transport in the Netherlands by using stated preference method. They studied SP survey for road, rail, air, and sea freight transportation in Sweden. They gathered data included variables of cost, time, transport time reliability, departure and arrival time, and interviewed 812 shipping companies. The results showed that in relation to the value of transport time, in shipping companies' point of view the cost components of transport (vehicles and labour) are important and this is while in owner of the goods point of view Those who contract, the freight components (financial issues related to the goods themselves) are most important.

Wang et al. [35] investigated measuring truck travel time reliability using truck probe GPS data. They categorised reliability based on GPS data into two groups: travel-time-based reliability measures and travel-time-based metrics. The proposed GPS spot-speed-based approach in Wang's study can alleviate the sample size constraint, and it does not require data processing from spot speed to travel time estimates. However, it is not able to provide a quantitative means for ranking and comparing reliabilities. The results showed that the assessment of reliability on a particular segment during periods depends on the reliability measures used.

Shams et al. [36] examined the value of travel time reliability (VOR) in freight transportation through a meta-analysis analysis. They paid a great deal of attention to the different design components of Stated Preference surveys in various studies, and in order to evaluate reliability, compared the results of different studies. The results showed that the estimated VOR values were largely different in various studies; this was probably due to the use of different units, different reliability measures, and survey design methods. They also examined the challenges and problems of cost estimation studies on the reliability of the time of freight transportation. Among the constraints, the inadequacy of data has been mentioned as a major obstacle to the progress of studies.

Duan et al. [37] presented freight network design with heterogeneous values of time. The paper employs the single allocation p-hub median problem which minimises the total generalised transportation cost (time, distance, etc.) with given demands. VOT is assumed to be discretely distributed, and estimated by mean-dispersion model and Latent Class model, based on a Stated Preference survey conducted in China. The results showed that the VOT and its distribution should be taken into account for better simulating railway shippers' heterogeneous valuations of service time versus time.

Larranaga et al. [38] studied freight intermodal transport encouragement through a stated preference analysis of freight mode choice in Rio Grande do Sul. The results showed that the shippers significantly value the fulfilment of delivery time and cost. Simulation results suggested investments for increasing the reliability of intermodal alternatives are more effective to encourage intermodality than cost reductions. Policies and investments to encourage multimodality should prioritise the increase of intermodal alternatives reliability and combined policies of cost reduction and reliability.

Goenaga and Cantillo [39] investigated the willingness to pay for freight travel time savings. They compared the framework of analysis of passenger values of time estimation known as random valuation (RV) with random utility (RU). Results suggest that the RV models performed better for the same dataset than its counterpart RU in all cases. Another aspect to highlight is that the freight value of time estimation value obtained with the RU approach was pretty similar to those obtained with the RV in most cases.

Keya et al. [40] presented a joint model of freight mode choice and shipment size. They adopt a closed form copula-based model structure for capturing the impact of common unobserved factors affecting these two choices. Also, they explore both the random utility (RU) based multinomial logit and the random regret (RR) minimization based multinomial logit (MNL) within a copula-based model. The shipment size is analysed using ordered logit (OL) model within the copula structure. The estimation results showed that there is a strong interconnectedness between shipment mode and shipment size choice decisions.

Duan et al. [41] studied the freight service network design with heterogeneous preferences for transport time and reliability. They presented a new frequency based service network design model with transshipments, capacity constraints and heterogeneous users. A case study is conducted for a railway network in China. Values of time and reliability are estimated from a recent Stated Preference survey and used to determine distinct user classes. Results showed that by taking variations in shippers' VOT and VOR into account, users' total generalised cost is reduced while service levels improve.

Kocatepe et al. [42] studied the value of freight accessibility through a spatial analysis in the Tampa bay region. They developed a Value of Freight Accessibility (VoFA) metric for traffic analysis zones (TAZs) as a function of accessibility to warehouses, number of trucks, and VOT. Results indicated that there is a need for smart transport solutions such as dedicated truck-only lanes, and Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) in order to help decrease the travel time needed for freight transportation and increase the freight accessibility.

2.3. External Costs

Golob and Regan [43] investigated road congestion adversely affects trucking operations in California through a survey from approximately 1,200 managers of all types of Trucking Companies. In the study, they used a Structural Equation Modelling (SEM) to estimate the difference between each of the five aspects of congestion (slow average speed, unreliable travel time, driver frustration and morale, fuel and maintenance costs, accident and insurance costs) on the various sectors of the road freight transportation (such as multi-modal transport operations and refrigerated trucks transportation). Also, the results showed that three factors of road congestion include: (1) unreliable travel time (2) driver's frustration

and morale, and (3) slow average speed had the most effects on congestion of road freight transportation.

Nash and Sansom [44] in a study compared the social costs of road and rail transport with current user charges in Europe. The purpose of the study was to investigate the pricing and performance policies in the European countries and measuring marginal and social related costs and related issues and obstacles to its implementation. The analysis includes infrastructure, vehicles, congestion, crash, and pollution costs. Estimates showed that automobile use generally covers costs, but under prices with respect to marginal costs.

Piecyk and McKinnon [45] studied on internalising the external costs of road freight transport in the UK. The ratio of total cost internalised varied by vehicle class, with the lightest category of rigid vehicles covering only 55% of their allocated costs, but the heaviest rigid vehicles covering 79%. In general, their analytical results show that tax on vehicles should be increased by about 50% to fully internalise infrastructure, environment and congestion costs. About 40% of total external costs are related to congestion, 23% to infrastructure, 19% to traffic accidents, 8% to greenhouse gases, 7% to other air pollution and 2% to noise pollution.

Gorman [46] in a study evaluated the public investment mix in the United States freight transportation social costs through trucks and rails (including congestion, safety, and pollution). The results show that governments currently spend an annual \$18.7 billion on road freight transport, which subsidises 24% (not paid by users), and public investment in rail transport will generally be more effective in external costs.

Delucchi and McCubbin [47] reviewed the external costs of transport in the US. Their research generally covers external costs, including road, rail, air and water transport; passenger and freight transportation; and congestion, accidents, air pollution, climate change, noise, water pollution, and security-energy costs. Findings show that, firstly, per passenger-miles or ton-miles, road transport modes usually have more external costs than others. Secondly, the highest external costs are accidents and congestion, and then there is air pollution and climate change costs. Government Accountability Office (GAO) [48] in a study compared the external costs of road, rail and waterways freight shipments. The analysis shows that freight transport by trucks leads to much more external costs (in terms of infrastructure, air pollution, accidents, and traffic) relative to rail or waterways shipments. Their research estimates that the external costs of road transport (trucks) are at least 6 times higher than rail and 9 times than waterways per tonne-mile.

Perez-Martinez and Vassallo-Magro [49] examined the changes in the external costs of freight surface transport in Spain. The results show that during this period, the external costs of road freight to climate raised by 16%, as opposed to air pollution and accidents, which dropped by 51% and 44%, respectively. The external costs of rail-related to pollutant emissions and climate increased 4% and 43%, sequentially. By contrast, the external costs for accidents decreased by 27%. Furthermore, their findings indicate that road freight generates eight times the external costs of rail, 2.35 Euro cents per tonne-kilometre in 2005 (5.6% accidents, 74.7% air pollution and 19.7% climate) versus 0.28 (13.4% accidents, 53.9% air pollution and 32.7% climate).

Austin [50] investigated freight transport pricing to account for external costs including maintenance costs on roads and bridges, delays caused by traffic congestion, injuries, fatalities, and property damage from accidents; and harmful effects from exhaust emissions in

the United States. The findings suggest that policies such as a raise in the existing tax on diesel fuel, implement a tax on the transport of shipping containers, or increase the existing tax on truck tires would shift a 3.6-percent-tonne-mile from truck mode to Rail and a 0.8 percent reduction in total freight tonnage.

Santos [51] studied the effects of tax changes on road transport fuel on the negative effects of road freight transportation costs in 22 European countries. His focus was on diesel or gasoline cars and diesel fuel freight vehicles. The findings indicated that some European countries have adopted policies that cover all external costs through internal taxation on gasoline and paid by users. On the other hand, tax on diesel fuel taxes seems to be lower than gasoline in all those countries. He suggested that an increase in fuel tax could be used as a short-term policy and for long-term, accurate policies such as peak hourly pricing or premium payments for driving rates could be arranged.

Mostert et al. [52] investigated the impact of operational costs and air pollution external costs in the Road and intermodal transport performance. They analysed the effect on modal split between road, intermodal rail and intermodal inland waterway (IWW) transport of several economic or environmental policies. Results showed that rail and IWW transport perform better than road regarding human health external costs. The external costs' minimisation strategy led to a configuration where intermodal transport has the most important market share. On the contrary, the operational costs minimisation strategy defines road transportation as the most competitive mode.

Kelle et al. [53] evaluated the operational and environmental sustainability trade-offs in multimodal freight transportation planning. They built a system-level intermodal simulation model that includes highways, railways, and waterways and also, evaluated the performance of the freight network under different scenarios and measured the benefits of mode changes evaluating the trade-off between environmental goals and other performance measures.

Dente et al. [54] studied the Impacts of trade related sustainability strategies on freight transportation for France. They calculated the impacts on freight flows using a new interregional transport model that includes distribution chains and produces estimates of external costs of transport. Results indicated that circular and functional economies could lead to a 2–5% reduction of air pollutant emissions and up to a 14–26% reduction if combined with the internalisation of external costs.

Nocera et al. [55] presented options for reducing external costs from freight transport along the Brenner corridor. The current modal split in the studied region tended heavily towards road (71% road – 29% rail), and the objective is to achieve (29% road – 71% rail) by 2035. This paper calculated the savings of external costs deriving from the achievement of this objective. The results showed that if the aggregated data from 2015 to 2035 are considered and the Euro region scenario is compared with a prosecution of the current trend, the saving in external costs would amount to €262 M (–26% than the current trend), which is equal to 4.7% of the annual public expenditure incurred by the Autonomous Province of Bolzano.

Vierth et al. [56] presented a comparison of external costs of trailer freight transport in the sea and road. They used both Sweden's national guidelines for cost–benefit analysis (ASEK) and the European guidelines (Ricardo). The results showed that the external costs for a road and shipping option are estimated to be lower than for the direct shipping

option under Swedish guidelines, but higher under the European guidelines. Also, indicated that the Swedish guidelines (ASEK) could be improved by incorporating specific values for air pollution from ships (particularly NO_x emissions) and a system for regularly updating emission factors.

Resat and Turkey [57] presented a bi-objective mixed-integer linear optimisation model to analyse the intermodal transportation systems in the Turkish transportation industry. The model is solved using two different exact solution algorithms, ϵ -constraint method and one direction search (ODS), to minimise total transportation cost and carbon dioxide emissions. They use six real-life case data in their optimisation model to obtain Pareto solution, enabling the logistic companies to make decisions based on cost, time and environmental factors in intermodal freight transport.

Carlan et al. [58] studied the quantifying of environmental performance of operational cost-reducing practices in road freight transport. They analysed the cost-effectiveness of innovative solutions highlighting both the costs and the environmental emissions they save. Results show that by using special types of chassis, which enable the combination of transport tasks in round-trips, the operational costs are reduced by 25–35%, and equally the CO₂ emissions are also decreased by 34–38%.

Kumar Dadsena et al. [59] proposed an integrated fuzzy failure modes and effects analysis (FMEA) for the selection of the most proper risk mitigation strategy for sustainable trucking industry. First, the risk factors are identified by analysing the existing literature and by involving transporters. The subsequent study and the developed mathematical model allow guiding the decision-makers to more conscious and sustainable choices.

3. Comparative Analysis Cost Estimating Studies in Freight Transportation

An extensive search for valid studies was conducted. Only studies with clear results of freight transportation cost elements were included in this study. Based on this search, 50 studies were identified from different regions of the world including the United States, Europe, North America, South America, and Asia.

Table 1 summarises the key features of these studies including their intended mode, costs class, geography of interest and freight cost estimation technique. The considered publications also are broken down by mode.

As shown in Table 1, in this paper, we investigate the state of the practice for freight cost estimation for the various modes of transportation. Out of the 50 unique publications which reviewed, 25 focus on road users, 10 on rail and road freight, 2 on rail, 2 on road, rail and air, 5 on Road, Rail and water, 1 on Road and water, and 4 on all road, rail, air, and waterways freight transportation together. The Figures 1–3 show the analysis of investigated studies in point of cost types and cost analysis methodologies.

As shown in Figure 1, road freight transportation costs are classified into three types from investigated studies including operational costs, the value of time and externalities. Figure 2, show the investigated studies classification by cost analytic methodologies. The cost analytic methodologies identified from literature are contained activity base costs (ABC), statistical models, surveys, Data-Mining, Metha-Analysis, and GIS. In Figure 3, road freight transportation costs are classified by the frequency of cost analytic methodologies from investigated studies.

Table 1. Summary of the studied publications on freight cost estimation.

Study	Mode				Costs Class			Geography				Methodology								
	Road	Rail	Air	Water	Operational	Value of Time	Externalities	Europe	United State	North America	South America	Asia	ABC	Mathematical	Statistical	Survey	Data Mining	GIS	Meta-Analysis	Other
Accent and Hague Consulting Group [25]	✓					✓		✓							✓	✓				
Austin [50]	✓	✓					✓		✓						✓					
Bolis and Maggi [29]	✓	✓				✓		✓							✓	✓				
Bruzelius [28]	✓	✓	✓			✓		✓								✓				
Brinckerhoff [10]	✓	✓	✓			✓		✓								✓				
Carlan et al. [58]	✓						✓	✓												✓
Conrad and Joseph [23]	✓				✓				✓							✓				
Danielis et al. [31]	✓	✓				✓		✓							✓	✓				
De Jong et al. [34]	✓	✓	✓	✓		✓		✓							✓	✓				
Delucchi and McCubbin [47]	✓	✓	✓	✓			✓		✓										✓	
Dente and Tavasszy [54]	✓						✓	✓						✓						
Duan et al. [37]		✓				✓						✓			✓	✓				
Duan et al. [41]		✓				✓						✓			✓	✓				
Fowkes et al. [30]	✓					✓		✓								✓				
GAO [48]	✓	✓		✓			✓		✓								✓		✓	
Goenaga and Cantillo [39]	✓					✓					✓				✓					
Golob and Regan [43]	✓						✓		✓						✓					
Gorman [46]	✓	✓					✓		✓								✓			
Holguin-Veras and Bromm [19]	✓				✓				✓				✓		✓					
Hooper and Murray [24]	✓				✓				✓						✓					
Janic [16]	✓				✓		✓	✓							✓					
Kawamura [26]	✓					✓			✓						✓					
Kelle et al. [53]	✓	✓		✓	✓		✓		✓											✓

(continued).

Table 1. Continued.

Study	Mode				Costs Class			Geography					Methodology							
	Road	Rail	Air	Water	Operational	Value of Time	Externalities	Europe	United State	North America	South America	Asia	ABC	Mathematical	Statistical	Survey	Data Mining	GIS	Meta-Analysis	Other
Keya et al. [40]	✓	✓	✓	✓		✓			✓						✓					
Kocatepe et al. [42]	✓					✓			✓									✓		
Kordnejad [11]	✓	✓			✓		✓	✓							✓					
Kulović [12]	✓				✓			✓							✓					
Kumar Dadsena et al. [59]	✓						✓													✓
Kurri et al. [27]	✓	✓				✓		✓							✓					
Larranaga et al. [38]	✓	✓		✓		✓					✓				✓	✓				
Levinson et al. [17]	✓				✓								✓							
Lindsey et al. [20]	✓				✓				✓						✓		✓			
Massiani [33]	✓	✓				✓		✓							✓					
Mostert et al. [52]	✓	✓		✓	✓		✓	✓											✓	
Musso [14]	✓				✓			✓								✓				
Nash and Sansom [44]	✓	✓	✓	✓			✓	✓							✓					
Nocera et al. [55]	✓	✓					✓	✓					✓							
Perez-Martinez and Vassallo-Magro [49]	✓	✓					✓	✓							✓					
Piecyk and McKinnon [45]	✓				✓		✓	✓					✓							
Qiao [21]	✓				✓		✓	✓						✓						
Radhakrishnan and Anukokila [13]	✓				✓		✓	✓						✓						
Resat and Turkey [57]	✓	✓		✓			✓					✓								
Santos [51]	✓						✓	✓							✓					
Shams et al. [36]	✓	✓	✓	✓		✓		✓	✓		✓	✓							✓	
Trego and Murray [18]	✓				✓				✓							✓				
Vierth et al. [56]	✓			✓			✓	✓	✓											✓
Wang et al. [35]	✓					✓			✓						✓					
Zamparini and Reggiani [32]	✓	✓				✓		✓		✓									✓	
Zhang [22]	✓				✓								✓							
Zofio et al. [15]	✓				✓			✓		✓							✓	✓		

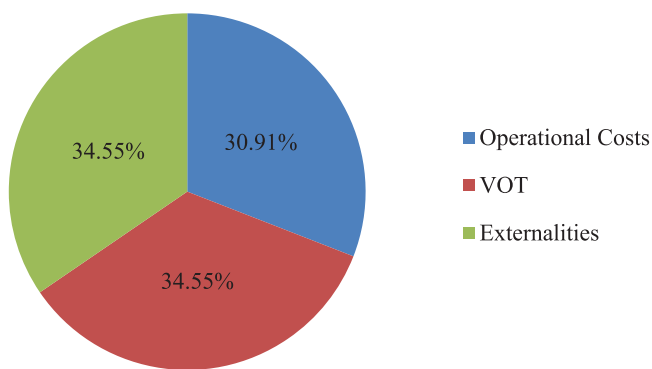


Figure 1. Percentage of investigated studies by costs type.

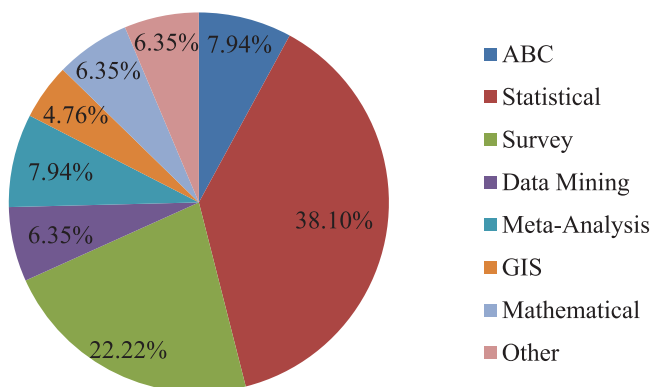


Figure 2. Percentage of investigated studies by cost analysis methodologies.

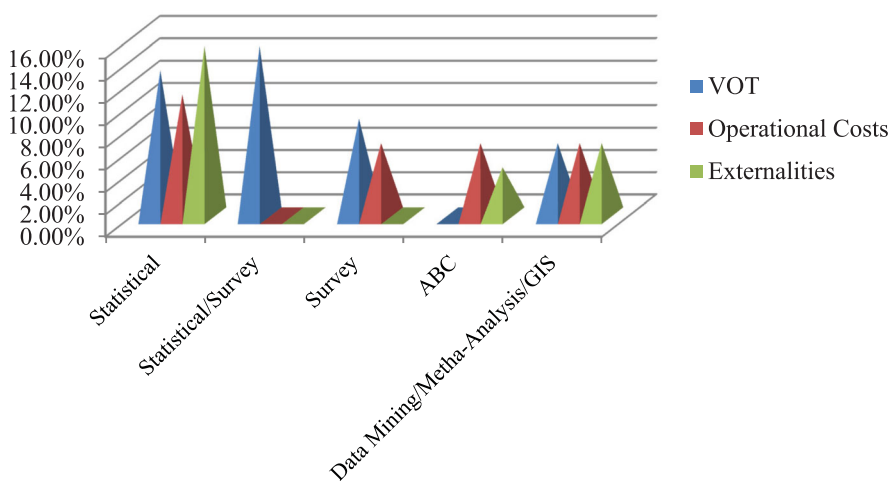


Figure 3. Percentage of investigated studies by costs/methodologies.

4. Model Structure

There are presented two model structures in this paper, (1) Road transportation costs (2) Road transportation cost estimating methods and data gathering.

4.1. Model Structure of Road Transportation Costs

The proposed model in this study aims to determine the road freight transportation types of cost and cost factors. The model is designed to identify any gaps between the types of cost or any inconsistencies in cost factors. This model consists of an overall structure and multiple substructures.

The model distinguishes three types of costs:

- (1) Operational costs – Operational costs are those expenses incurred in the daily running of a business. These are internal to the carriers and include both fixed and variable costs. variable costs are incremental costs that can go up or down based on the amount of business activity or consumption. By contrast, fixed costs do not change depending on the level of activity or consumption. Labour, fuel, vehicle maintenance, insurance, initial purchase of vehicles/rolling stock, handling costs, and a range of government taxes and charges, including fuel excise and vehicle registration are some examples of operational costs.
- (2) Value of time – these factors are the value of non-monetary costs such as travel time and service quality costs. At the time of decision making, the value of time factors such as reliability and travel time will impact on shipping company selection and transportation modal choice.
- (3) External costs – These costs are not directly borne by the exporter and can cause a divergence between the costs imposed on society and the decision facing the exporter. Environmental, congestion, and accident costs are external costs examples.

Figure 4 illustrates the overall model structure and how each of the components sums to the total freight transportation costs.

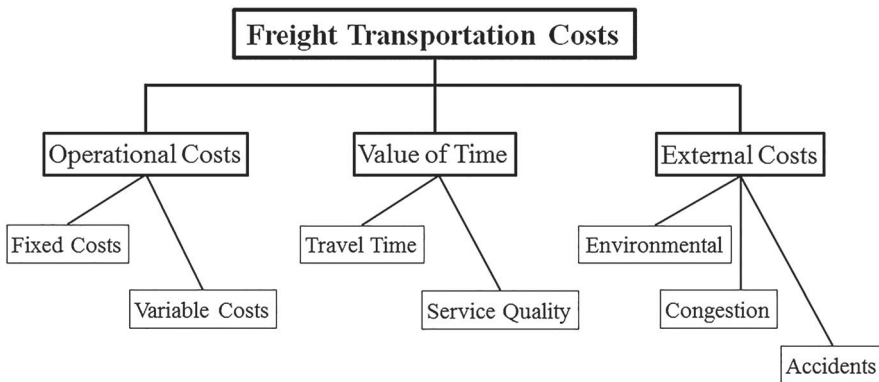


Figure 4. Overall model structure of road freight transportation costs.

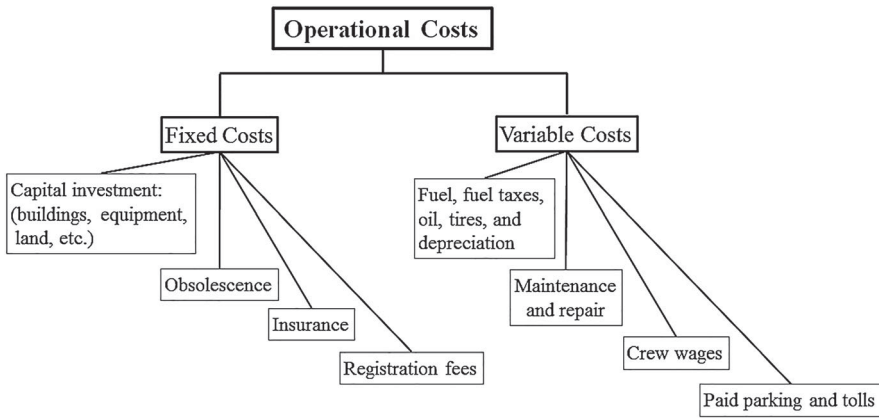


Figure 5. Model sub-structure – Operational costs.

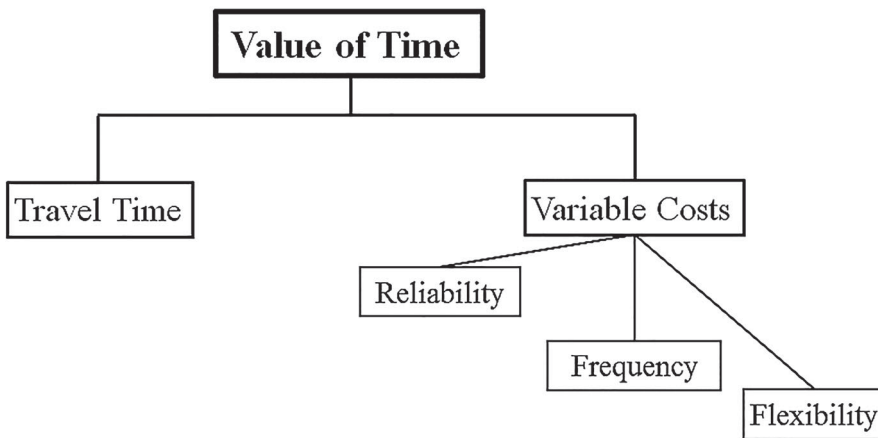


Figure 6. Model sub-structure – Value of Time.

Figure 5 illustrates the various sub-components of the operational costs of road freight transportation.

Figure 6 illustrates the various sub-components of Value of Time cost factors of road freight transportation.

Figure 7 illustrates the various sub-components of external costs of road freight transportation.

4.2. Model Structure of Road Transportation Cost Estimating Methods and Data Gathering

The second proposed model determines the road freight transportation data analysis methods and data gathering suggestional sources.

Figure 8 illustrates the overall model structure of Road Freight transportation cost estimating methods and data gathering.

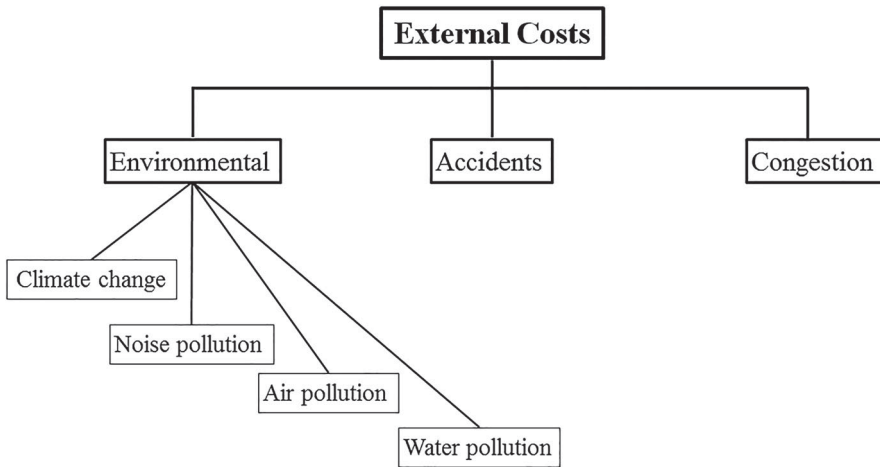


Figure 7. Model sub-structure – External Costs.

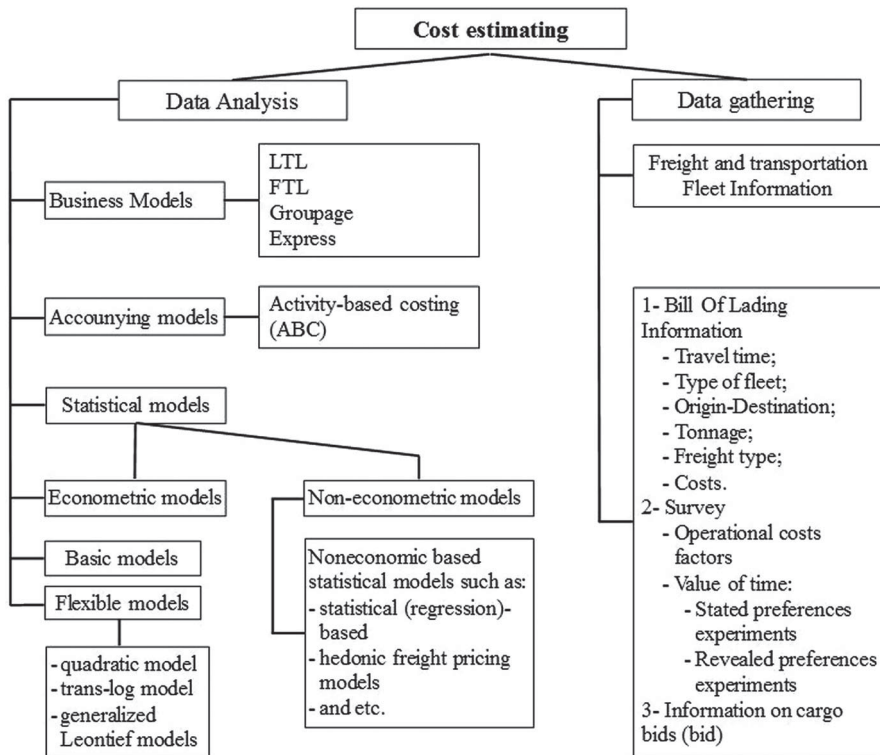


Figure 8. Road Freight transportation cost estimating methods and data gathering.

5. Conclusion

In this paper, we investigate the state of the practice for freight cost estimation for the various modes of transportation by focusing on road freight transportation costs

elements and cost estimating methods. Also, two model structures were proposed; (1) Road transportation costs (2) Road transportation cost estimating methods and data gathering.

From road transportation costs model structure, the reviewed studies are generally divided into three categories in terms of cost factors including operational cost studies, value of time saving and external cost studies. Each of these studies includes specific cost factors that can be briefly described as follow:

- (1) Operational cost factors, which include fixed and variable costs. Fixed costs are not affected by the amount that the vehicle is used and are included vehicle excise duty, vehicle insurance, operator's license fee, drivers' guaranteed wages, depreciation, and overheads. Variable costs depend on the actual use of the vehicle and are such as fuel cost, lubricants, tires and repairs and maintenance.
- (2) Value of time factors. These variables are the qualitative variables in which if the customers are sensitive to them, they are more willing to pay more to the freight forwarder. The most important of these factors is the 'delivery time' and 'reliability' quality.
- (3) External cost factors. These variables include those that freight transportation imposes on the community such as environmental pollution, traffic congestion, noise pollution, accidents, etc.

Through reviewed studies, 17 articles were related to operational costs, 19 about value of time, and 19 about external costs. An overview of each of the articles and their key features including their intended mode, costs class, geography of interest and freight cost estimation technique is presented in Table 1.

Most of the operational cost studies were about road freight transportation while most studies related to VOT have examined the cost changes in intermodal systems especially road and rail and road, rail and waterways systems [10,28,29,31–34,36,38,40,50]. In the case of external cost studies, most researches have compared the costs of all different modes of freight transportation.

The cost estimating methods and data gathering model structure includes all cost estimating functions and proposal data gathering sources extracted from the reviewed articles. Through analysed studies, 38% were statistical modelling methods, 22% were survey methodologies, 8% were accounting-based methods, 8% were meta-analysis studies and the rest of them were data mining, GIS, mathematical and other methodologies. The share of each methodology in the reviewed studies is presented in Figure 2. In this paper also, road freight transportation costs are classified by the frequency of cost analysis methodologies from investigated studies and the share of each methodology is shown in Figure 3. Here are some of the most commonly used methods: from the Figure 3, the statistical methodologies have the most used in external cost studies with a share of 15.22%. The survey methodologies have the most used in VOT studies by share of 8.70%. The accounting-based methods have the most used in operational cost studies.

The most important methodologies from estimating methods and data gathering model structure in general are; (1) Accounting-based and (2) statistical modelling method.

- (1) The most commonly used accounting methodology is the Activity Based Costing (ABC). The major limitation of this method is the impossibility of replacing the data. In other

words, with the change in the freight flow transportation scenarios, it is not possible to determine and predict pricing in the model itself.

- (2) Statistical methods are divided into two categories of economic models based on econometric theory and models other than the econometric theory. Econometric models are divided into two basic and flexible models. In the meantime, considering that flexible models, as well as other than economic theory models due to the freedom in modelling and variables, do not create any restrictions on cost functions for statistical modelling, are more proper to use in freight transportation cost estimating.
- (3) For qualitative data which is unmeasurable, such as the value of time and reliability, we can use methods that analyse the preferences of goods owners, customers, and operators, such as revealed preferences (RP) or stated preferences (SP).

6. Suggestions for Future Research

This paper reviewed 50 studies in the field of cost factors and cost functions of freight transportation. From this study a lack of some research has been identified that could be studied in the future:

- Meta-analysis studies were only used in external cost and VOT studies in reviewed researches and there is limited authentic meta-analysis research in the case of operational cost studies.
- Little research has been carried out on the pricing policies and pricing models of road freight transport, which could be of interest to researchers.
- Since freight transportation costs are not constant values, the use of fuzzy methods in modelling could help to make the results more accurate, which methodologies of the previous studies have shown the lack of fuzzy methods in this regard.

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No potential conflict of interest was reported by the author(s).

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