3rd International Conference on Energy and Environment: bringing together Engineering and Economics
Porto, Portugal
29-30 June, 2017

Sustainable Public Transportation from a Total Cost of Ownership Perspective

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KEYWORDS
Public Transportation, Value of travel time, Total Cost of Ownership, Green Transportation, Sustainability.

ABSTRACT

Green transportation advocates decreasing use of private motor cars, the increasing use of walking, bicycle and public transport. Since the main factors for people who desire to travel are cost and time, the use of private cars has increased with significant negative impacts on environment. Total Cost of Ownership (TCO) is an analysis meant to uncover all the lifetime costs that follow from owning certain kinds of assets. In the near future, more people will be challenged to use a combined set of transports to minimize total transportation costs. In this study, a set of combined types of transportation (private cars, train and bus) was simulated by using a traffic simulation software and the TCO for a case of a route in the North of Portugal was calculated. Criteria for the evaluation of the different types of transportation included conventional cost of traveling (internal) and value of travel time and value of environmental aspects proceed by the CO_2 emissions (external costs), all translated in monetary values using estimations of the value of time and of environmental impacts. The results showed the importance of the value of time estimation and confirmed public transportation as the best option under both conventional and extended TCO point of view.

1 INTRODUCTION

By 2050, the World Health Organization estimates that at least 70% of the world's population will live in cities (Lee 2014). Cities need to identify new strategies to increase quality of life of their citizens while maintaining economic competitiveness. Urban population growth and rapid urbanization have generated an increasing freight transportation demand within cities. These phenomena cause environmental and mobility problems linked to air pollution and traffic congestion (Benjelloun and Crainic 2009; Browne et al. 2012). As a result of various influencing factors, European freight transport demand has faster increased, approximately 80% in the period 1990-2008. In the year 2009, the transport sector was responsible for about 24% of the total Greenhouse Gas (GHG) emissions in the European Union. Within the transport sector, road transports are the main sources of GHGs emissions representing 17% of total GHG emissions in Europe (European Environment Agency, 2011). Green transportation advocates decreasing use of private motor cars, the increasing use of walking, bicycle and public transport, and the use of clean energies and vehicles. Using green transportation alternatives, instead of utilizing private motor cars, is a low-cost, pollution-free, land resource and space saving transportation system suitable for all kinds of travellers (Li 2016). Since the main factors for people who desire to travel are cost and time, the use of private cars has increased with significant negative impacts on environment.

Total Cost of Ownership (TCO) is an analysis meant to uncover all the lifetime costs that follow from owning certain kinds of asset. Thus, TCO is sometimes called life cycle cost analysis. Asset ownership brings purchase costs, of course, but ownership can also bring large costs due to installing, deploying, using, upgrading, and maintaining the same assets. Consequently, for many kinds of assets, TCO analysis finds a very large difference between purchase price and total life cycle costs. And, the difference can be especially large when ownership covers a long time period. Most of previous presented transportation models have considered the conventional TCO that estimates the cost of acquiring and operating a vehicle across the entire period of ownership (Garfamy 2006; Hagman et al. 2016; Richard West 2004; Rusich and Danielis 2015). However, in conventional TCO, external costs, such as environmental impacts or the value of time are missing. In order to compare public with private transportation and obtain a sustainable transportation model, both conventional TCO and external costs should be considered.

In this study, a set of combined types of transportation (e.g. private cars, train and bus) was simulated by using a traffic simulation software (AIMSUN) in one of the most important connections of Portugal, namely the cities of Porto and Braga. Accordingly, a TCO including both time and environmental externalities was computed.

A set of scenarios is presented to obtain a sustainable and effective transportation model for people who want to travel from their origin (house or work place) to their destination (house or workplace) in Braga or Porto. The considered comparative criteria for the evaluation of the different types of transportation include: conventional cost of traveling, value of travel time and environmental aspects (CO_2, NOx) translated in monetary values using estimations of the value of time and of environmental impacts.

2 LITERATURE REVIEW

As shown above, the total cost concept is not new. In 2011, Michalek et al. assessed the TCO incurred to own and operate various types of vehicles plus the cost of the oil and damages caused by lifetime emissions charged to the owner at the time of purchase, assuming no change in driving patterns. They find that HEVs (hybrid electric vehicles) have an advantage over conventional ICE (internal combustion engine) vehicles (Michalek et al. 2011). Another interesting research in TCO is about the increasing use of electric vehicles in Germany in order to reduce greenhouse emissions; the target of the German government to have at least one million electric vehicles registered by 2020 seems currently far from realisation. For this reason, the author analysed the total cost of ownership (TCO) of electric passenger vehicles in Germany on a component-based approach and gives an estimation about the further development until 2050. To represent the German market, they investigated different vehicle sizes, user types and drive technologies. Furthermore, they show the CO_2 abatement potential offered by different types of electric vehicles (Bubeck, Tomaschek, and Fahl 2016).

Travel time is one of the largest categories of transport costs, and time savings are often the greatest expected benefit of transport improvement projects. Factors such as traveller comfort and travel reliability can be quantified by adjusting travel time cost values (Victoria Transport Policy Institute 2012). Table 1 summarizes typical values of time used for transport project evaluation in Europe (Hessen 2004).

Table1: Value of Travel Time in Europe

Interurban	€ 6.40 per person hour
Road	€ 6.00 per person hour

The Value of Travel Time (VTT) refers to the cost of time spent on transport. The Value of Travel Time Savings (VTTS) refers to the benefits of faster travel that saves time (Victoria Transport Policy Institute 2012). The value of travel time savings (VTTS) is central in transport economics and transport policy. Still, it is a remarkably elusive concept, since the VTTS varies across situations and individuals. The VTTS varies both with socioeconomic characteristics, such as income, family situation and employment status, and with trip-related characteristics such as time of day, trip purpose and comfort aspects (Börjesson and Eliasson 2014).

Transport has a considerable impact on the environment, mostly representing externalities. For example, the emission of CO_2 of traffic contributes to global warming. In the medium and long term, this can result in negative health impacts and in external environmental costs (Hessen 2004).

Beginning in the 1990s, several studies were performed to evaluate different traffic simulation packages and their ability to adequately simulate various test networks and transportation system configurations. In general, simulation is defined as a dynamic representation of some part of the real world achieved by building a computer model and moving it through time (Drew 1968). AIMSUN is a widely used commercial transport modelling software, developed and marketed by TSS- Transport Simulation Systems based in Barcelona, Spain. Microscopic simulator and Mesoscopic simulator are the components of AIMSUN that allow dynamic simulations. They can deal with different traffic networks: urban networks, freeways, highways, ring roads, arterials and any combination thereof(Transport Simulation Systems 2010). Several traffic simulation models have been developed for different purposes over the years. In order to validate the simulation models as effective and appropriate tools, many studies have contributed to simulator evaluation. Most of these studies were qualitative and were based on feature availability (Alexiadis, Jeannotte, and Chandra 2003; Boxill and Yu 2000; Schmidt 2000).

3 RESEARCH METHODOLOGY

In order to obtain the Total Cost of Ownership (TCO) to uncover all the lifetime costs of traveling for people who desire to travel from their Origin to their Destination and vice versa, not only the conventional cost of traveling but also travel time and environmental aspects (represented by the CO_2 emissions proxy) are considered in this research. Thus, the comparison of three types of transportation; traveling by private cars, bus and train between various origins and destinations would be closer to reality. The proposed model is demonstrated to the case of a route connecting to major cities in the North of Portugal, where the Origin will be different zones of Porto and the Destination will be different zones of Braga.

In this study, three models were implemented in the AIMSUN software:

- Central train station of Porto (Sao Bento) to Central train station of Braga (intercity):

- The population of Porto city is around 214,579 and the Population of Braga is around 181,502 inhabitants (Instituto Nacional de Estatística 2014). These two cities are two of the most populated cities in Portugal, so the amount of traffic among these cities is highly relevant. Usually, in one hour around, 1,000 cars would travel between these two cities (Sistema de Monitorização do Ar e Ruído 2008). The distance of this route is about 50 km in each ways, and this was simulated as a freeway route.

- Intracity of Braga:
  The origins of people who want to travel from Braga to Porto would be in different zones, because of that in this research three zones based on distance of origins from Central train station of Braga were considered:
  - Origins which are located less than 1 km from Central train station of Braga:
    In this study it is considered that these people would choose walking to train station.
  - Origins which are located between 1 to 6 km from Central train station of Braga:
    In order to obtain indicators such as travel time, conventional costs and CO_2 emissions, a specific rout of 5 km was assumed corresponding to University of Minho in Braga to Central train station of Braga.
  - Origins which are located more than 6 km from Central train station of Braga:
    Another route of 7.5 km connecting Bom Jesus location and Central train station of Braga was assumed.

  Since Braga does not have subway, for the last two cases (intracity routes) people would be traveling by private car or public transport (bus).
- Intracity of Porto:
  The last model would represent Porto city, like Braga three centroids were considered for Porto:
  - Origins which are located in less than 1 km from Sao Bento train station of Porto:
    In this study it is considered that these people would choose walking to train station.
  - Origins which are located between 1 to 6 km from Sao Bento train station of Porto:
    For this type of origins, a specific 6 km route connecting Estadio do Dragao (Football Stadium) to Sao Bento train station.
  - Origins which are located in more than 6 km from Sao Bento train station of Porto:
    For this type another rout of 16 km among Porto Airport and Sao Bento train station was assumed.

  Since Porto has a subway, for the last two intracity routes people would could be traveling by private car, bus (STCP) or subway.

Building a transport simulation model with AIMSUN is an iterative process that comprises three steps: model building, model verification and output analysis (Barcelo, 2011).

- **Model building** is the process of gathering and processing the data and inputs to create the model.
  Building an AIMSUN model requires two kind of information:

  1- Supply data, that is everything related to infrastructure and services that allow people to travel coded as a graph, such as geometric and functional specification of the road network (road shape and number of lanes), public transport services and maximum speed.
  In this study, geometric information has been gathered from: Google Earth, Google Maps and Open Street Map.
  Information about Public Transport by bus inter the cities (Braga and Porto) has been collected from TUB Company (Transportes Urbanos de Braga) and STCP Company (Serviço de Transportes Coletivos do Porto). Finally, data about public transport between Porto to Braga and vice versa has been gathered from Rede Expressos Company.
  In the first model (Sao Bento Central train station in Porto to Central train Statin of Braga) which is a freeway, maximum speed is considered to be 120 km/h. In his route 3.25 euros are included as a highway toll (AENOR Portugal).
  The number of passengers for private cars as assumed to be 2 in each travel, for road bus 40 passengers were considered and for intracity buses the value of 25 passenger per travel. The rate of fuel consuming by each car was defined: 5.5 L/100km for the speed less than 90 km/h and 6.5 L/100km for the speed between 90-120 km/h. In addition, the rate of diesel consumption for public transport buses inter the cities is considered between 15-20 L/100km and for buses that travel between Porto and Braga this rate is about 25-35 L/100km (Pascal Wolff and Jukka Piirto 2017).
  Furthermore, as mentioned before in the literature, for the value of travel time for road transportation it was considered 6.00 euros per person hour and for intracity transportation 6.40 euros.
  In the second and third model, which are InterCitys, road type was defined as an arterial and maximum considered speed is 50 km/h.

It should be mentioned that CO_2 emissions for train was set as 27.03 gCO_2/(km. passenger) (Comboios de Portugal 2014) and CO_2 emissions in road transport were valued as 0.03-0.04 EUR/kg (European Parliament; European Council 2009).

2- Demand data that is related to mobility needs to be included in the simulation, was coded as a set of OD (Origin-Destination) matrices. In our model, origins and destinations are Central station de Braga (Braga Train Station) and Sao Bento de Porto (Porto Train Station) in the first model, University of Minho, Bom Jesus and Central station of Braga in second model, finally Estadio do Dragao in Porto, Porto airport and Sao Bento train station are the ODs of the last model.

- **Model Verification, Calibration and Validation,** that is a fundamental part of traffic simulation by AIMSUN. It is the process of confirming that the implementation of the models logic is correct; setting appropriate values for the parameters and comparing the outputs of the model to corresponding real world measurements that are Google Earth, ArcGIS, Google maps, etc., in order to test validity.

4 RESULTS

Output analysis in AIMSUN is the exploitation of model outputs in line with the overall objectives of the modelling study. After the implementation of the three models and running the software, a set of results was produced for each model. These results, which includes the calculation of TCO are presented in Tables 2 to 4. Table 2 describes the results of the first model, Sao Bento train station in Porto to Central train station in Braga. Table 3 describes the results of the second model, University of Minho to Central train station in Braga and Bom Jesus to Central train station in Braga. Table 4 describes the results of the third model, Estadio do Dragao to Sao Bento and Porto Airport to Sao Bento train station of Porto. TCO values are shown in Tables 2, 3 and 4. The values were obtained by from the software and computation of the initial data which was elucidated in supply model section and literature review. In order to obtain TCO, all indicators including travel time, fuel cost, ticket price and CO2 emissions were converted to cost values (€).

Table 2: TCO values for each passenger in Porto-Braga route.

Indicator	Private Car	Bus	Train
Travel Time (€)	4.6	5	7
Highway toll Cost (€)	3.25	-	-
Fuel Cost (€)	3.5	-	-
Ticket Price (€)	-	6	3.15
Value of CO_2 emissions (€)	0.09	0.02	0.001
TCO	11.44	11.02	9.15

Table 3: Braga TCO values for each passenger.

	University of Minho to Central station		Bom Jesus to Central station	
Indicator	Private Car	Bus	Private Car	Bus
Travel Time (€)	0.85	1.81	1.28	2.45
Fuel Cost (€)	2	-	3	-
Ticket Price (€)	-	0.7	-	1.4
Value of CO_2 emissions (€)	0.02	0	0.02	0.01
TCO	2.87	2.52	4.30	3.86

Table 4: Porto TCO values for each passenger.

	Estadio do Dragao to Sao Bento			Porto Airport to Sao Bento		
Indicator	Private Car	Bus	Subway	Private Car	Bus	Subway
Travel Time (€)	1.70	2.13	2.13	2.56	3.73	4.80
Fuel Cost (€)	2	-	-	3	-	-
Ticket Price (€)	-	1.5	1.2	-	2	2
Value of CO_2 emissions (€)	0.02	0.01	0	0.03	0.02	0
TCO	3.72	3.64	3.33	5.59	5.75	6.80

For all of the analysed cases, the travel time cost plays a fundamental role on decision making representing, in some cases, the most relevant criteria for the computation of the TCO. This is particularly the case of the route Porto Airport to Sao Bento station route, whose travel time plays a significant role since traveling by Subway takes two times more than traveling by private car, and after gaining the TCO for this particular route, TCO value for private cars is less than

Subway and bus. This is particularly evident for the case of train and subway as travel time costs are higher than the internal costs which were assumed to be equivalent to the ticket price. This is mainly due to the longer travel time of train and the assumed differentiated VTT for different transportation means. On the other hand for private cars the internal costs related to fuel and highway toll exceed the external costs. As for the case of buses, the relationship is not as evident. For the case of intercity the ticket price exceeds the travel time cost but for the intracity values, the travel cost is considerably higher than the internal costs.
The public transportation values tend to be lower than the private car, either considering only internal costs or including also external ones. The only exception goes to longer subway routes in Porto, which are penalized by the longer travel time. As for the environmental aspects, private car is always the worst option and train and subway are always the best ones.

5 CONCLUSIONS

People who desire to travel between Porto and Braga would have three modal choices: private car, bus or train. Private car is more comfortable and faster than other modes, but results in negative impacts to environment because of fuel consumption. The others modes are cheaper and have less negative impacts to environments, but can result in higher travel time. By calculating the Total Cost of Ownership, it seems that the best way for traveling from Porto to Braga and vice versa is using bus from various centroids in Braga to Braga train station, using a train between Porto to Braga and using a subway or bus between different centroids of Porto to Sao bento train station.
The results of this study are highly dependent on the assumptions taken and as such highly uncertain. In particular, the value of travel time was assumed to be independent of the transportation mean; however, the way people use their time during travel should have a high influence on this value and as such transportation options that could allow for a better use of time (leisure or business) can lead to a lower VTT, and, consequently, to a lower TCO. In the same way, time of the day, especially the peak hours of a day; 07:45-09:45 am and 17:15-19:15 pm can influence both internal and external costs of each transportation option. This study opens then several avenues for future research, namely a risk analysis of all these factors showing the sensitiveness of the results to these assumptions and the probability assessment of the TCO for different cases. Furthermore, another important factors which can be considered in a future research are noise and convenience rate by transport mode. Moreover, the study should proceed with the demonstration of the possible use of the results for helping the strategic decision-making of public transport companies, e.g. design of new tariff schemes.

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