Faster, Cheaper, Cleaner
Assessing Urban Mobility

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Abstract: This work aims at systematically characterizing urban mobility. There are several possible approaches to the problem but this work focus on reducing commuting times and emissions using the current infrastructures and without increasing the cost to the end user and doing so in an effective and sustainable way. A set of pairs of destinations and origins was chosen to represent usual commutes and cover a significant area of a city. These locations were connected by car, motorcycle, public transportation, cycling and walking. The routes were performed in both directions at three different times of day which allowed for a better understanding of daily traffic variations. For each route and for each mode of transportation the route and time taken were collected and the emissions and cost were estimated . The data was treated to adjust the route and gradient difference between the collected data and actual roads. Measurements and estimates were compared and averaged for all the routes and for each means of transportation providing an overall view of the commutes. The different means of transportation were compared and the limit to which one mode has the advantage over another was evaluated, this advantage is however dependent on the chosen route.

1 INTRODUCTION

The current fast growth of urban population is likely to lead to an unsustainable situation if not handled properly. This increase creates multiple problems not seen before, being mobility one of the most affected areas.

New emerging urban mobility problems cannot be tackled effectively using traditional solutions. Innovative approaches and creative solutions are needed to tackle this ever increasing problem.

This paper aims at analysing one such approach and present some preliminary results and findings. The focus was mainly on the analysis of soft and shared means of transport and how could they be beneficial to the population in three different areas: time, cost and emissions.

2 MOTIVATION

Historically, the solution to urban mobility problems are based in the construction of more roads, bigger infrastructures and the displacement of industries and services to unused areas close to the cities. However with the fast growth of the urban population (World Health Organisation, 2010) and the increasing cost of land these solutions are no longer efficient.

However, to tackle this new problem, one must first have the means to analyse and quantify it. While several methodologies exist (Tomtom, 2013; Gabinete de Estudos e Planeamento and Direcção Municipal da Via Pública, 2007) to evaluate mobility in urban areas they do not consider nor optimize for an intermodal route calculation with different weights of cost, emissions, distance travelled and commuting time.

The proposal for this project was to try to develop an index that included considerations for time, emissions and cost for a certain route travelled in urban areas. The methodology could then be used to evaluate and compare urban mobility in different areas of the city and different cities.

3 METHODOLOGY

To ensure the coherence of the results and their ap-

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plicability to other cities and to different contexts, a structured approach was defined. These methods could then be used to analyse and then compare different cities.

Due to geographical proximity and presence of multiple modes of transport the city of Porto was chosen as a testbed for the pilot. Several routes were selected and analysed using the different available transport modes.

The gathered data was analysed using available web tools, some of the data was estimated using values from available sources.

The overall methodology (cf. Figure **??**) consists of a first selection routes and gathering of data followed by the definition of mobility models that would allow to expand the analysis to other areas and therefore validate the models. The process would be continuous and cyclic to improve the model as well as evaluate the mobility within the city.

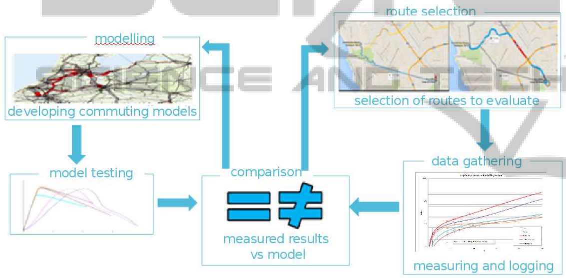

Figure 1: Methodology overview.

3.1 Modes of Transport

The project considered multiple means of transport within the city of Porto. The modes of transport should represent the most commonly used and allow for different scenarios to be evaluated.

The evaluated modes of transport were:

- Car;
- Motorcycle;
- Public Transport (Rail and Road based);
- Bicycle;
- Pedestrian.

Using these different modes of transport allows for a greater understanding of the mobility in the city and considers most of the available options to the citizens.

3.2 Route Selection

In order to have a pilot for the methodology different pairs of origins and destinations within the urban area of the city of Porto were selected. The different pairs should be connected by public transport and have access by the other means of transport.

The criterion for selection of routes was as follows:

- The routes should cover the biggest area possible;
- The routes should have connections by public transport;
- The routes should connect the most travelled from and to areas of the city.

After an analysis with the municipality of Porto, the selected routes were as follows:

- From the city hall to CEiiA's building in Matosinhos
  - Connects the city center to an important adjacent city. Multiple interfaces exist between the two cities. It is an important connection for the two cities
- From Casa da Música to the Faculty of Engineering
  - Connects an important multimodal interface and entry point of the city with a widely used area close to the outskirts of the city and to one of the most important hospital of the city
- From Campanhã's train station to the hotel area near Avenida da Boavista
  - Connects one of the major entry points to the city with a area with good access near the city center and good opportunities for visitors
- From Anemona's Roundabout to Ribeira
  - Connects two areas on the outside of the city bypassing the center. Usual route for tourists and citizens going to the riverside area

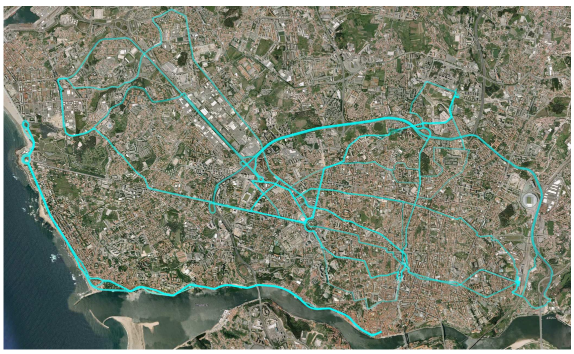

Figure 2: City of Porto with routes connecting origins and destinations highlighted.

Using the modes of transport defined in chapter 3.1 and the selected pairs of origins and destinations, a total of 320 km within 20 unique routes were identified (cf. Figure 2). Figure 2 shows that the almost totality of the city area is covered providing a testbed extensive enough for the purpose of this work.

3.3 Data Collection

To evaluate the parameters considered for this paper GPS data for all routes was collected.

3.3.1 GPS Data

The GPS data was collected using GPS Logger for Android, a smartphone application (cf. Figure 3). This application records points along the route in CSV (Comma Separated Values) format.

The recorded GPS data is extensive, however, within the scope of the project only some information was used. Table 1 describes the data collected with the GPS application.

Table 1: Data collected from the GPS Logger.

Data type	Units
Time	Hours,Minutes,Seconds
Latitude	Degrees
Longitude	Degrees
Altitude	m
Speed	m/s

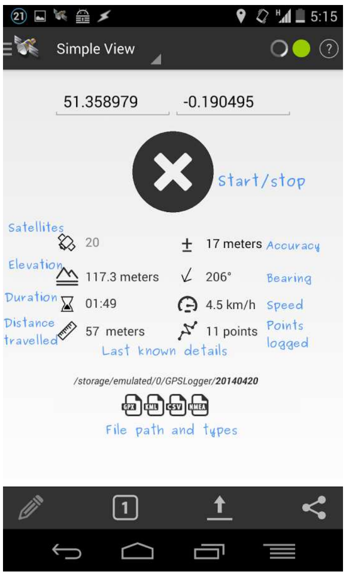

Figure 3: Screenshot from the GPSLogger Application.

The data collected will allow to define the exact route used to connect the origin to the destination and the time taken to travel such route.

3.4 Estimates

Some of the parameters could not be directly measured and were therefore estimated or used from other sources.

The use of estimated values for part of the results is needed due to the constraints of the problem and the high complexity required to measure some values.

This is acceptable because the project focuses not on a particular type of displacement but tries to average and create an approximate model for cost, time and emissions. However to ensure the validity of the results the number of sources was kept to a minimum.

3.4.1 Costs

Within the scope of this paper the cost estimation considered those that directly affect the user and were calculated as a function of distance. Public transport was the exception as the costs for the user are not a function of distance but depend on the number of travels necessary to take. This would give an approximate value for each mean of transport that could be used for comparison along their route.

For car the cost per kilometre was obtained from the Portuguese legislation (Portugal, 2012) since it defines the value that should be paid by companies to their employees when using the private car for work related travels. It was considered that during the making of the law an extensive study was done so as to define a fair value that included not only gas, but also vehicle maintenance, wear, insurance and taxes. The value should reflect the average cost per kilometre of the global Portuguese car fleet (Balsa, 2013).

For motorcycle the value was also obtained from the Portuguese Legislation (Portugal, 2010) due to the reasons presented above.

For public transport the cost is not a function of distance but instead depends on the number of trips. Both rail and road based transport in the city of Porto have the same cost and use the same tickets. One single-use trip in the city of Porto has a cost of 1.20 euros. However, considering a daily commute with two trips (home-work and back) for 22 days of work per month and a public transport card costing 30.10 euros per month would result in a cost of 0.64 euros per trip.

Cycling has a cost of 0.03 euros per kilometre considering maintenance for a lifetime of 10 years according to the working paper on the Costs and Benefits of Cycling (Belter et al., 2013).

The cost of walking is negligible and considered to be zero. Although one could argue shoes and clothes are deteriorated while walking, their cost cannot be attributed to the activity itself as people have to buy clothing and shoes anyway. Recent reports (Fundação Calouste Gulbenkian, 2014) have shown there are even potential savings in terms of healthcare costs, as walking regularly does reduce the risk of cardiovascular diseases and diabetes, for instance. However, it is difficult to quantify direct savings and for the purpose of this study the authors decided not to consider them.

Overall the obtained estimated cost values for each mode of transport were:

Table 2: Cost estimation per mode of transport.

Transport	Cost
Car	0.36€ per km
Motorcycle	0.14€ per km
Public Transport	0.64€ per trip
Bicycle	0.03€ per km
Pedestrian	0€ per km

3.4.2 Emissions

For this project emissions were not measured due to the granularity of data required and the project timespan. To ensure that the model represented the actual Portuguese car fleet (Balsa, 2013) extensive measurements had to be made and those would produce results highly dependent on the driving style (Panis et al., 2006).

More comprehensive models like the COPERT and MOVES were not used due to some problems, the MOVES model does not represent the Portuguese car fleet (Duarte and Costa, 2010) while the COPERT model does not have a data set representing Portugal individually, only as part of the EU (Emisia, 2014).

Furthermore emission estimation can introduce a great overhead if not properly evaluated, therefore, within the scope of the work only the equivalent CO2 emissions for each mode of transport were considered.

Car emissions were obtained from the Carbon Footprint Calculator (Carbon Footprint, 2012) for a EU average petrol car with an engine up to 1.4L. The value obtained was of 160.61 grams of CO_2 per km. It is considered that this value reflects the average car from the Portuguese fleet and therefore is adequate.

Motorcycle emissions were obtained from the same source as the car ones (Carbon Footprint, 2012) and the value obtained is 106.21 grams of CO_2 per km.

Public transport emissions need to consider both road based and rail based public transport. A previous work done by Quercus (Portuguese Environmental Agency), with results available online (Ecocasa, 2012). For road based public transport the value is 82 grams of CO_2 per km while for Portos rail based transport system is 63 grams of CO_2 per km.

The European Cyclist Federation (European Cyclist Federation, 2012) states that cycling emissions are around 21 grams of CO_2 per km.

For this paper it was considered that walking produced no emissions.

Overall the obtained estimated emission values for each mode of transport were:

Table 3: Emission estimation per mode of transport.

Transport	Emissions
Car	160.61 gCO_2 per km
Motorcycle	106.21 gCO_2 per km
Road-based Public Transport	82 gCO_2 per km
Rail-based Public Transport	63 gCO_2 per km
Bicycle	21 gCO_2 per km
Pedestrian	0 gCO_2 per km

4 DATA ANALYSIS

Using the collected and estimated values for each mode of transport and pair of source and destination the data was analysed to perceive patterns that would allow to generate a model that could be extended to other routes with different characteristics. The collected GPS data was converted from CVS to GPX format to be easier to interpret with mapping applications.

Due to errors induced by the measurements the data points were fitted to the road to more correctly represent reality. For each pair of source and destination the time taken and estimated cost and emissions were evaluated for each mode of transportation. The results were then averaged for all routes to give an overall vision of the city along those 3 vectors.

The obtained results were extended to a model where the cost, emission and time can by evaluated for each mode of transport over distance (cf Figures 4,5, and 6)

Using the results obtained and the analysis along each individual vector, an index that comprehends the three parameters was developed. This index considers different weights for time, emissions and cost that can be tuned for different values (cf. Equation 1).

$$\begin{aligned} Index = Average(&Time \times Weight, \\ &Distance \times Emission \times Weight, \\ &Distance \times Cost \times Weight) \end{aligned} \tag{1}$$

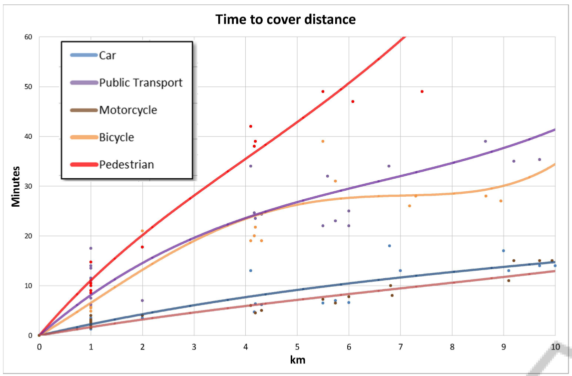

Figure 4: Time over distance.

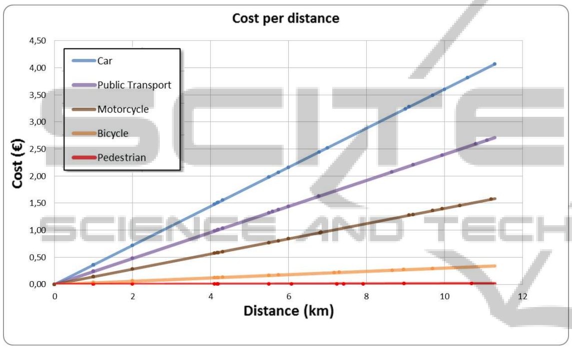

Figure 5: Cost over distance.

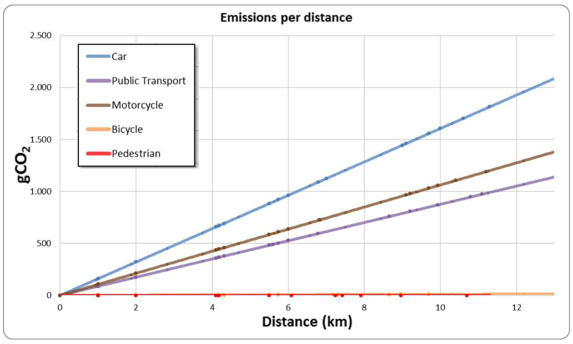

Figure 6: Emissions over distance.

With this index value for each distance the results can be extrapolated and values for all distances can be obtained.

A urban commuter such as a businessman will make the mode of transport choice with most of the weight on time. A possible weight distribution for such user would be: 98% for time, 1% for emissions and 1% for costs. With this distribution, car and motorcycle are the best options up to 10 km. After that, cycling is the best option, due to the small accumulating effects of cost and emissions in the index, nevertheless these results are based on trend lines and can be change once further data gathering is done. After

Figure 7: Triple Parameter Mobility Index versus distance (lower is better) for 98% time, 1% emissions and 1% costs.

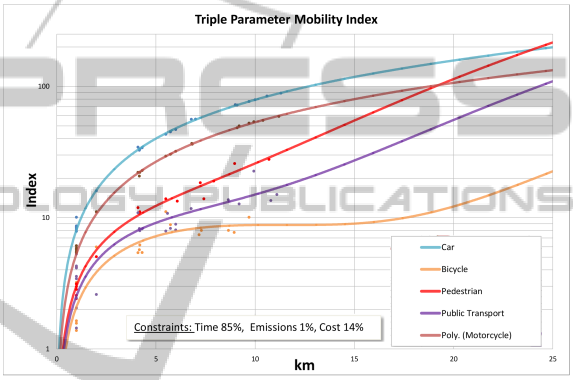

Figure 8: Triple Parameter Mobility Index versus distance (lower is better) for 85% time, 1% emissions and 14% costs.

20 km motorcycle becomes the best option. Public transport is one of the worst options for the evaluated distances.

A typical middle class worker will consider that time is of importance but cost will also be an important factor therefore the weight distribution will be: 85% for time, 1% for emissions and 14% for costs. In this case, cycling is always the best option while the car is the worst. Cycling is almost two times better than a car for the evaluated distances. Public transport is, again, worse than cycling. Walking, although worst than cycling is still better than driving up to 20 km, without considering other external factors, as fatigue for instance.

An urban commuter with great environmental conscience would consider emissions to be the top priority. A possible weight distribution for such commuter would be: 25% for time, 50% for emissions and 25% for costs. In this situation, bicycle and walking are always the best option. Due to the high weight for emissions all other modes of transport are worst. Public transport is again the least desirable mode of transport. However, when considering a zero emission vehicle, such as an electric vehicle, the car is again the

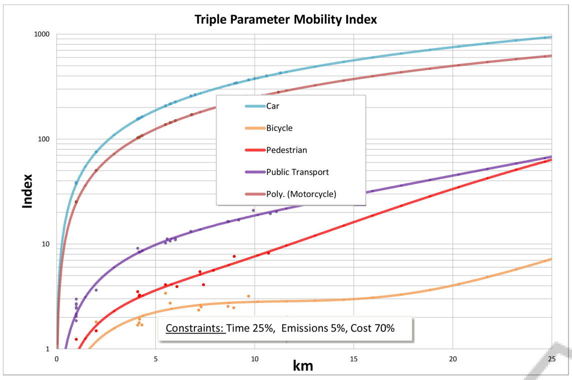

Figure 9: Triple Parameter Mobility Index versus distance (lower is better) for 25% time, 5% emissions and 70% costs.

best option, since not only the emissions will be reduced but the costs as well.

5 CONCLUSIONS

After evaluating the obtained results it can be seen that cycling, contrary, to what was expected is faster than public transport while being cheaper and less pollutant.

Car is one of the fastest modes of transport, however is the most pollutant and expensive. However this only considers one occupant per car, a higher number of occupants per vehicle could make car a better option. This opens the possibility for further studies considering the impact of urban car-pooling schemes in commutes.

The index shows that without a considerable weight for time, car is never the best option. Cost has a great influence on the index. Public transport is rarely the best option, it is however a valid mode of transport if one cannot walk or cycle over long distances.

Public transport might have a bad performance due to the lack of dedicated lanes for road based public transport. While rail-based public transport is not affected by traffic and has a better performance than cycling the overall results of public transport are negatively affected by the poor results of the road based counterpart. In further studies, rail and road based public transport modes should be analysed separately.

It might be possible that electric assist bicycles could further improve the advantages of cycling over public transport. However further studies need to be made.

While the selection of the city of Porto as a case study provides an insight on the methodology to evaluate the urban mobility, however further studies in different cities are recommended as a validation tool for the methodology.

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