BICYCLES: SUSTAINABLE TRANSPORT OR HAZARDOUS DEVELOPMENT

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ABSTRACT

The use of bicycles is quite recommended in many countries. It is considered as a healthy and sustainable mode of transportation. Sustainable development requires the mix of three - environmental, social and economic aspects. The objective of this article is to demonstrate that bicycles riding does not always present net social or economic benefits, and hence should not be praised as sustainable.

The analyses of both, social and economic features of bicycles riding, are done through the determination of economic break-even points between car and bicycle usage under different trip characteristics.

For the social impact analysis, costs of fatalities and severe accidents are calculated for different transport modes. The research considers differences in the usage of these modes of transport, in terms of annual mileage and average number of passengers.

The economic comparison considers vehicle operating costs as well as the value of travel time. Unitary results are compared. Several charts, under different assumptions, determine boundary conditions of preference between bicycles and other modes.

The results of the research point out clearly that in social or economic terms not always bicycle riding is superior to other modes. The findings demonstrate that the network and usage of bicycles should be carefully planned and applied, in order to provide safe conditions for bicycle riding. As well, for some trip purposes, car was found less expensive than bicycle.

The direct implication of the research, regarding bicycle development, is the strict recommendation for the need of safety facilities for bicycles networks.

The research is based on general data. Hence, its conclusions should not be taken for granted and must be carefully adapted to local conditions.

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INTRODUCTION

The use of bicycles is encouraged by public agencies in many countries. Schepers and Heinen (2013) indicate that "Policy interest in promoting a shift from car to bicycle trips has increased substantially in recent times". Bicycle is considered a healthy and sustainable mode of transportation. A considerable campaign is set up in order to promote the use of bicycles as an alternative mode of transportation and as a healthy option of leisure activities. One main justification of the use of bicycles is the presentation of this mode as a sustainable one. The meaning of sustainable requires several characteristics, that some of them are not always fulfilled by bicycles transport.

One highlighted characteristic of bike riding is its inferiority to any other mode of transport (except motorcycles) from the point of view of road safety and accidents severity. We will show that the most severe risk in bicycle riding (i.e. death risk) is up to ten times greater than in other modes of transport, such as car or public transport.

The principal analysis tool that we will present in this article is the economic evaluation. Using the method of break-even point calculation it will be shown that in some cases, depending upon costs criteria and the value of time, bicycles are not an economic mode of transportation. It should be noted that these cases, where bicycles are economically better or lesser than other modes, are important in order to determine barriers in terms of trip conditions and trip purposes in which bicycles are superior or inferior to other modes of transport.

Sources for information and literature regarding the economy of bicycle riding are scarce. Thus, a considerable part of cost estimates, investments and other economic characteristics were calculated from row data in this research.

Safety considerations, especially concerning the "value of life" are very touchy. Many will oppose any value assigned to lost life, arguing that this value should be infinite.. However, estimating the economic value of life became a common practice applied by transport economists, even though this value should always be considered as socially underestimated.

The essence of the paper is divided into three chapters:

- A literature review, which analyzes the basic terms of the methodology used and the sources of costing data. In this part a reference to the classification of bicycles riding as sustainable transport will also be analyzed.
- The methodology, explaining the nature of a break-even point analysis, its components and the various variables that are included in the break-even point determination.
- Results and recommendations. This part begins with some applications of the break-even point method. Several charts are presented, including the impact of future fuel costs and changes in the value of time. The analysis is concluded with a set of conclusions and recommendations of the research.

LITERATURE REVIEW

The use of bicycles is widely recommended in many countries. It is considered a healthy and sustainable mode of transportation. In some cases, the terms of sustainable and green development are confused. Adams (2006) defines that sustainable development requires the mix of three - environmental, social and economic aspects. "Green" development belongs mainly to the environmental component. In this article we will show that encouraging bicycle riding does not always serve the social aspects of development, and not always it is economic. Hence, it should not be considered as a sustainable development.

There is no doubt about the fact that bicycles are better than motorized vehicles from the environmental point of view. Bicycles contribute to human health and create an unrestricted mood. As well, the use of bicycles reduces pollution and encourages a clean appearance of the transportation nature.

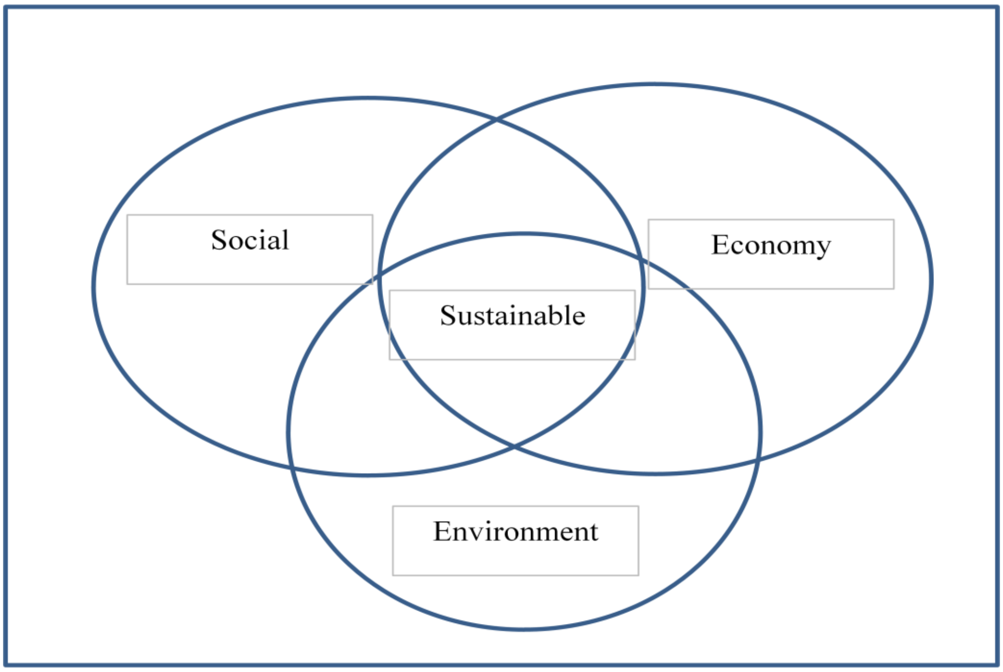

Figure 1: Components of sustainable Development

Source: Based on Adams (2006)

The analysis of the social point of view has to consider both, traffic accidents, in terms of number and severity on one hand and the impact on equity on the other. Schepers and Heinen (2013) argue that for short trips the number of deaths in bicycles accidents is not bigger than in cars. There is no doubt about the importance of the infrastructure assigned to bicycles (Lin and Yang, 2011). In general, many studies do not include equity as one of their objectives. We should always bear in our mind that there are people who are not allowed to use cars due to medical reasons or because they cannot afford it.

In the frame of this paper, the component of "economic" will be defined in money terms, through the calculations of vehicle operating costs (VOC), the value of time (VOT) and accidents costs. The conversion to money terms is required in order to facilitate the comparison between alternatives. During the second half of the last century, the World Bank developed a computerized package aimed at the economic evaluation of road projects. The actual version of this package is called HDM-4 (Highway Development and Management model). The package includes, inter alia, a complete vision of vehicle operating costs (Archondo Callao and Faiz, 1997). In our research, some components of economic terms, as parking costs, pollution costs and congestion costs are not considered. These would obviously alter the calculated results in some situations. Nevertheless, they do not change the attitude of the general results.

The Department of Transport of the UK in the National Travel Survey (NTS) (2010) shows that less than 5% of trips use bicycles and that the overall distance travelled by bicycles is less than 2.5%. However, the amount of fatalities in bicycles accidents is almost one third of all fatalities in accidents in Europe (ICF Consulting, 2003). We can assume that the average cost of accidents in bicycles, for each unit of distance, is up to 10 times greater than in cars.

It is difficult to estimate per km cost of accidents for pedestrians. However, the average distance made by pedestrians is 3% of the total trips distance, and the number of fatalities is about 15% of the total (NTS, 2010). Hence, the cost of accidents for pedestrians should be about five times bigger than the average per passenger – km cost[2].

Costs were calculated according to various sources, for conventional fuel engine vehicles. I estimate that different energy prices (e.g. fuel, gas, electricity) will have similar increase tendency in the future. Not all scholars share the same opinion. Heather (2012) argues that there is no tight connection between gas prices and oil prices. She demonstrates that gas prices are increasing gradually, and increased in about 40% between 2009 and 2012 (less than 15% annually). At the same period of time oil prices had brusque changes and increased, through the last 10 years, in an average of 30% annually. In our research all calculations refer to gasoline and diesel engines.

METHODOLOGY

GENERAL OVERVIEW

As mentioned in the introduction, the main tool used in the analysis was the break-even point method. We will first discuss the characteristics of that method and its formation for the subject treated.

[2] This value is over-estimated, since the amount (and percentage) of walk trips is, almost always, underestimated. Hence, the cost estimated in the model, only doubled the cost used for car.

Break-even point method is generally used to distinguish among different alternatives. It permits to detect under which conditions certain solution or answer to a specific problem, presents advantages over other answers or alternatives. In terms of costs comparison, a prioritized alternative will offer the minimal cost among all alternatives.

In the study, we will consider four transportation modes: bicycles, passenger's car, public transport (represented by a regular 50 seats bus) and walk. In terms of the overall model the location of an optimal mode will be determined by the minimal cost.

$$OC = Min_i \{C_i\} \qquad (1)$$

$Where$: OC is the optimal cost among all modes i, i=1,4

Ci is the cost of mode i (e.g. bus).

Three questions may rise-up with respect to equation 1:

- What is the unit to which costs refer? Do we talk about an annual cost, hourly cost, trip cost or cost per kilometer (or mile).
- What is the set of variables which are included in the costs calculations.
- How do we deal with other variables that present costs or benefits but are not taken into account. These variables, with no doubt, may alter the results of the optimization.

Hereafter we discuss these issues.

The unit of costs

In order to compare different modes of transportation, we should refer to the production of the mode. In transportation, the production should be measured by passenger trips. However, it is obvious that long trips should be more costly than short ones. Hence, the correct term, that was selected, is passenger kilometer cost. Note that this definition implies several factors which should be taken into account. One is the occupational factor, or number of passengers per vehicle. While in the walk and bicycle modes this factor equals one[3], this is not the case for cars and buses. Moreover, these factors vary substantially between different countries. Another important consideration is the need to convert average annual and hourly costs into distance costs. All these transformations require data on average annual distance travelled and vehicles speeds. These factors will be discussed later.

The variables considered

Travel costs per passenger are affected by many variables. In this paper we divide them into several groups, while in each group a set of variables is determined. In the next paragraph we will mention other variables which are not taken into account in the study. The different groups and the variables included in each of them are presented in table 1.

Table 1: List of Cost Variables

Group number	Group name	Variables considered	Letter(s) assigned
1	Fixed costs	Vehicle purchase cost (Depreciation and Interest), Licenses fees, Insurance.	DI L I
2	Per Km. costs	Fuel Tires Maintenance Spare Parts Accidents costs, Environmental impact[4]	F T M SP A E
3	Per hour costs	Value Of Time Wages of crew	VOT W
4	Traffic variables	Average Speed Trip Length	AS TL

[3] In several countries in Asia and in Africa, the assumption of one passenger per bicycle should be carefully revised.
[4] Environmental impact is not considered in the cost function. This impact should increase the relative feasibility of bicycles.

Group number	Group name	Variables considered	Letter(s) assigned
		Annual Kilometrage traveled Occupational Factors Trip Purpose	AK OF TP
5	Economic variables	Life-Time Residual Value Rate of interest	LT RV R
	General	Cost per passenger	C

Later on, while defining the equations of the model, we use the letters assigned in the table for the different variables.

Variables which are not considered

One of the most recognized features of bike riding is its contribution to health and to the good mood of users. However, these are characteristics which are beyond the scope of the economic tools developed. However, it is recommended that these should be included in the analysis. Some information about the relative importance of these variables could be collected through stated preference surveys, using hedonic price or travel choice methods, to distinguish and calculate their quantitative values.

Another possible impact is the additional time required for parking. According to TDM Encyclopedia (2011), the average additional parking time for cars increases total travel time by about 11%[5]. In the case of public transport, waiting time and walk to and from the mode should be added to the "in vehicle" time.

COMPONENTS OF THE COST FUNCTION

In general, after transferring al costs components into per kilometer-passenger costs, the total cost (calculated separately for each mode) is:

$$C = fixed\ cost + \ per\ km.cost + per\ hour\ cost \qquad (2)$$

[5] I the research, car unit costs were expanded in order to consider thin effect.

The methodology to calculate each of these components is described in the following sections.

Fixed costs

In this group of costs we find a part that belongs to the life time cycle of the mode, and other components which refer to the vehicle's annual cost.

The depreciation and interest per kilometer passenger are calculated together according to the formula:

$$DI = K \cdot R \frac{(1+R)^{LT} - RV \cdot R}{AK \cdot OF((1+R)^{LT} - 1)} \qquad (3)$$

In equation 3, K is the price of a new vehicle and R is the rate of interest.

For licenses and insurance the formulas are simpler.

$$L = \frac{Fee}{OF \cdot AK} \qquad (4)$$

$$I = \frac{Pr}{OF \cdot}$$

Where Fee is the annual fee paid for licenses, and Pre is the annual insurance premium.

Per kilometer costs

For all per kilometer costs, a similar formula is applied. The following formula is for fuel costs per kilometer-passenger.

$$F = \frac{Fck}{OF} \qquad (6)$$

Where Fck is fuel cost per kilometer.

Per hour costs

For the transformation of per hour costs into passenger-km costs, average speed was applied. For all per hour costs the formulas are similar. Note that these values are already given per passenger (or driver). Thus, the calculation of the cost per passenger kilometer is (example of value of time is given):

$$VOT = \frac{HV}{AS} \quad (7)$$

HV in the formula stands for the hourly value of time.

It is worthwhile to note several remarks:

- Not all components of costs exist for all modes of transportation. For example, the "walk" mode of transport has merely the value of time component.
- Values of costs depend heavily on trip purpose and average speed.

COSTS ESTIMATES

BASIC TECHNICAL DATA

From equations 3-7 above one can deduce that four general parameters are needed for the comparison between the different types of vehicles. These are: vehicle life-time, average vehicle speed, annual distance traveled and occupation factors.

Table 2 presents these data for the four modes of transport considered.

Table 2: Basic data for the transport modes

Variable	Pedestrian	Bicycle	Car	Bus
Vehicle life-time (years)	(-)	5	10	12
Average speed[6] (Km/h):				
urban	4	10	25	20
rural[7]	4	20	70	70
Average annual kilometrage	(-)	1,300[8]	15,000[9]	60,000[10]
Occupation factor[11]	1	1	1.5	25

[6] The range of speeds for bicycles is based on El Geneidy et al (2006). For other vehicles and walking speed were based upon the common practice.
[7] The analysis in this paper refers merely to urban trips.
[8] The average **weekly** distance traveled by bicycle in the UK is 16 miles (NTS, 2010).
[9] Average annual distance traveled by car in Israel.
[10] Acording to FTA (2007), the average annual mileage of a bus is 37,000.

NEW VEHICLE PURCHASE COSTS

In the four modes of transport considered, "walk" does not include any investment cost. Each of the three modes:"car", "bus" and "bicycle", includes many types of vehicles. Hence, the new vehicle price selected for the study refers to a range of prices, which reflect the most used models. It is important to detect that the price of vehicle in New York is not equal to that in Kampala. Thus, we include in the analysis quite a wide margin for these costs. Basic prices were derived from different sources, mainly through internet web sites.

Prices of vehicles, especially those of passenger cars, are bound to various tax instruments, which tolerate the correct economic price of vehicles. However, certain tax level is acceptable as economic cost, since there some governmental activities are carried out to administrate the construction, safety and international transportation of vehicles. Since the goal of this article is not the definition of exact cost estimates, a set of prices, from different countries, was analyzed, in order to determine an acceptable range of these costs.

Prices vary according to type of vehicle, its size and its model. Bus prices differ according to length, type and number of seats. Prices are also sensitive to accessories which are installed in the vehicle.

It is interesting to know that not only in motor vehicles, but also in bicycles, gaps of hundreds percents, between different types and models, were found.

All these phenomena where analyzed, before applying the main model of the study.

Car purchase price

Prices of several types of cars were collected from the US, the UK, Mexico, Brasil and South Africa. . In order to present all costs in US dollars, prices were transformed to $US, using the rates of exchange. These rates are presented in table 3.

[11] Assumptions should be modify according to local circumstances.

Table 3: Rates of exchange versus $US as for September 15, 2012

Country	Currency	Value in US dollars
United States of America	Dollar	1.000
United Kingdom	Pound	1.620
Mexico	Peso	0.078
Brasil	Real	0.493
South Africa	Rand	0.122
India	Rupee	0.019
Australia	Australian Dollar	1.057
Israel	New Israeli Shekel	0.255

For each country, several representative cars and their prices were selected. A logical range of prices was determined. The ranges of costs, after the application of the rates of exchange are presented in US dollars in table 4.

Table 4: Purchase Prices of Passengers Cars[12]

Country	Representative cars	Lower limit of prices-$US	Upper limit of prices-$US
U.S.	Chevrolet Spark, Buick La Crosse, ford fiesta, Hyundai Tucson, VW golf, Toyota Corolla	12,000	28,000
U.K.	Hyundai i10, Ford Fiesta, Ford Focus, Mazda 3, Mazda 6, Ford Mondeo, VW Passat	14,000	29,000
Mexico	Seat Toledo, Suzuki Swift, Ford Fiesta, Chevrolet Aveo, Nissan Ultima, VW Golf	14,000	23,000
Brazil	Hyundai HB20, VW Gol, Fiat Punto, Ford Focus, Fiat Grand Siena, Honda Civic	14,000	25,000
South Africa	Chevrolet Spark, Chevrolet Sonic, Ford Fiesta, Mazda 3, Mazda 6, Toyota Corolla	12,000	25,000

Considering the above presented results, and considering the relatively high custom charges on cars, a range between 10,000 and 25,000 $US will serve as basic data for the model.

[12] Based on http//autos.yahoo.com, http//www.whatcar.com, http//autosactual.com, http//fotosecarros.com.br, http//vehicletrader.co.za.

Bus purchase price

A similar process was applied to bus purchase price as well. Considerable differences were found between Chinese buses (mainly Hyundai make) and others, mainly Europeans. A 50 seat Chinese bus is evaluated at a price between 77,000 and 110,000 $US. The price of South African Hino bus, of the same size, is about 150,000 $US. European makes, as Man and Mercedes, are valued between 190,000 and 200,000 $US. The European buses are slightly bigger that the others.

Hence, the range adopted for the evaluation was between 100,000 and 150,000 $US for a 50 seats bus.

Bicycles purchase price

A revision of bicycle prices shows a big variety of prices. The lowest price found is less than 100 $US and the most expensive price is over 20,000 $US. In the research a range of prices was determined, considering most popular bicycles. Table XXX presents values extracted from distinct sources and refer to different countries[13].

Table 5: Prices of Bicycles

	Local Currency			In $US
Country	Unit	Price Range	Frequent Price Range	Frequent Price Range
United States	$US	89 - 7,500	200 - 400	200 - 400
Australia	$AU	249 – 1,899	700 – 1,500	740 – 1580
India	Rupee	9,250-18,830	9,250 - 10,000	175 – 190
Israel	NIS	500 – 18,000	1,000 – 2,000	255 - 510

Based on the above data, a final range between $US 200 and $US 500 was defined for bicycle prices.

VEHICLES OPERATING COSTS

Cars

The American Automobile Association (AAA, 2006, table 1) presents values for vehicle operating costs. Based on these values the following table (considering medium sedan car) is set up.

[13] Based on http//shopper.cnet.com, http//www.bikes.com.au, http//www.filjog.com, http//zap.co.il

Table 6: Fixed Costs and Per Km Costs for Car ($US)

Per Km. Costs	Fuel	0.061
	Maintenance	0.030
	Tires	0.005
	Total per Km. cost ($/Km.)	0.096
Fixed Costs	Insurance[14]	902
	Licenses	551
	Total per year fixed cost ($/year)	1,453

Bus

Bus operating costs are determined in three main categories: per km. per hour and fixed costs. According to FTA (2007) per km. costs are 0.499 dollars. These are formed by 0.381fuel costs and 0.118 maintenance costs (tires costs are included in maintenance). Drivers salaries vary between $23,000 and $60,000 per year (www.indeed.com, 2012). Average suggested value is $35,000. This value equals $16 per hour. License and insurance rates were considered to be double than cars.

Bicycle

Operating costs of bicycles are negligible. Hence, no cost is assigned to this component in the model.

VALUE OF TIME

The determination of the value of time (VOT) varies according to countries and trip purpose. Even though, there is a general acceptance that the value of work related trips (i.e. a trip to a work meeting, traveling to buy working materials etc.) should be approximately the average hourly wage (Waters, 1992; Wardman, 1998; Ministry of Transport of Israel, 2006). The U.K. Department of Transport estimates that passenger's travel time savings average 6.6 pence per minute for commuting and 5.9 pence per minute for other trips (excluding business trips). These values are about six American dollars per hour, or approximately 15%-20% of the average wage. The Ministry of Transport of Israel (2006) estimates the value of time for work purposes

[14] When costs of accidents are considered directly, insurance (at least partly) should be ignored.

trips in about $15 per hour, while for commuting and leisure purposes values of $4.5 and $3.0 (30% and 20% of work related VOT, respectively) are assigned. An overall world mean wage is estimated at $4.86 (Oostendorp, 2008).

The range of VOT should be quite wide. It depends on the average per-capita income in the country as well as on the purpose of the trip. Hence, a range between $1 and $20 was selected for the analysis. Note that lower values correspond to developing countries and higher values to the developed ones. As well, lower values will be assigned to leisure trips and higher values to work related trips.

VEHICLES ACCIDENTS COSTS

Accidents costs include a combination of fatalities, injuries and damage to vehicles.

The Federal Highway Administration (1997[15]) estimated the costs of accidents of motor vehicles in the following values.

Table 7: Per vehicle-km costs of accidents in motor vehicles ($US)

Vehicle type	Per Km. cost in urban area	Overall Average per Km. cost
Car	0.024	0.036
Bus	0.035	0.055
Bicycle	0.120-0.240	0.180-0.360
Walk	0.048	0.072

Even though the data is not recent, the ratio between bicycles and car accidents is remarkable. Accidents costs in bicycles are estimated at a level between five and ten times higher than in cars. For pedestrians, the cost of accidents per Km. is double than in cars.

RESULTS AND CONCLUSIONS

RESULTS

The following table is **an example** of the calculation of per passenger-km. costs for the different modes. As stated before, many cost items should be modified according to local conditions. Note that lower limit of accidents costs was taken for bicycles.

[15] Taken from TDM, 2011.

Table 8: Example of overall per passenger-km. cost calculations ($US)

Mode	Walk	Bicycle	Car	Bus
Interest Rate (%)	10%	10%	10%	10%
Annual Kilometrage	1200	1300	15000	60000
Vehicle Life	70	5	10	10
Average Speed (Km/h)	4	10	25	20
Occupation Factor	1	1	1.5	40
Purchase Investment	0	250	10000	100000
Annual Capital Recovery	0	65.95	1627.45	16274.54
Annual Cost licence, Insurance	0	50	1453	2906
Per Km. Cost	0	0	0.10	0.50
Per km. accidents cost	0.048	0.12	0.024	0.035
Per Hour Vehicle Cost	0	0	0	16
Value of Time per Hour	5	5	5	5
Per Km. - pass. total cost	1.30	0.71	0.46	0.29

Data in table 8 were calculated according to the equations presented in the methodology.

The following chart compares the distribution of cost sources between bicycles and cars. Note the remarkable percentage of accidents in bicycles costs. This item is the main reason for the differences in costs between bicycles and other modes of transportation.

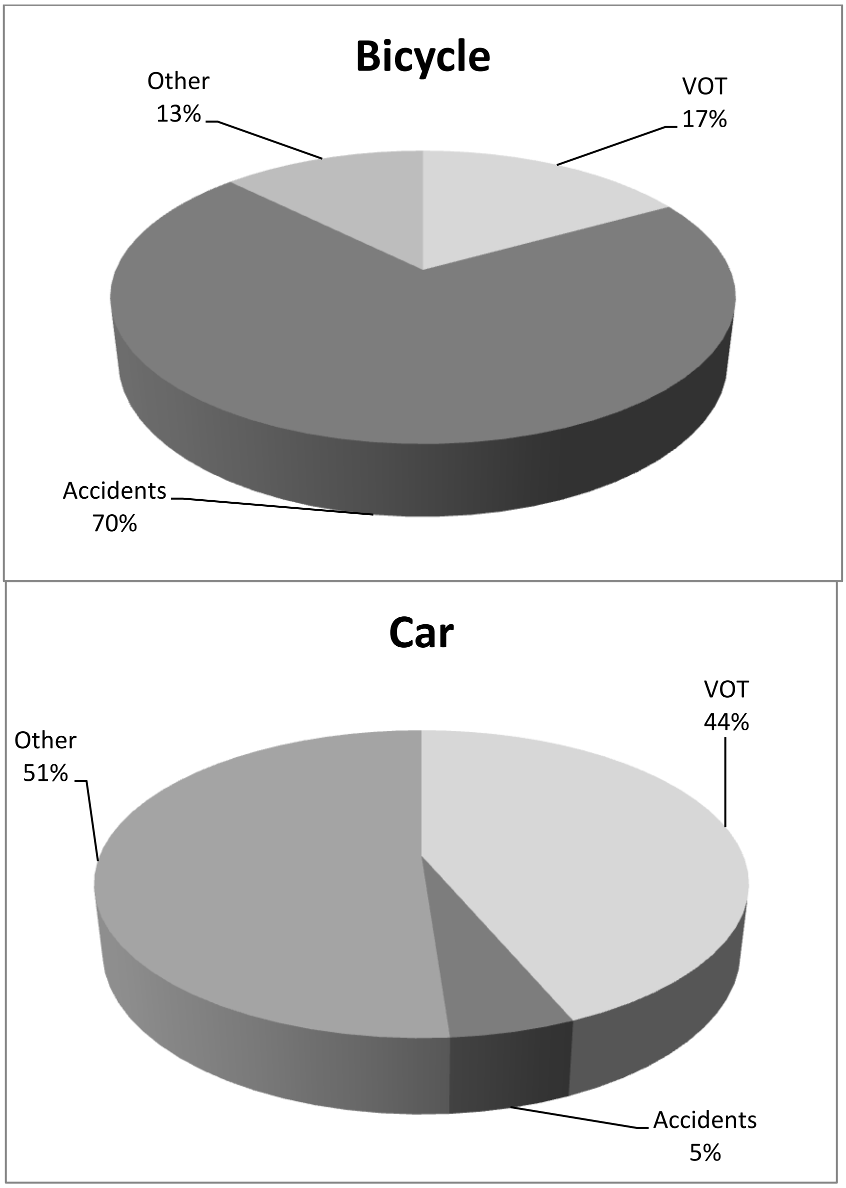

Figure 2: Distribution of cost elements per passenger-km for bicycles and cars

The following charts represent variations in the overall passenger-km costs due to changes in the essential variables which impact the overall travel cost.

Firstly, it is important to consider the impact of changes in the value of time (VOT) on the cost comparison.

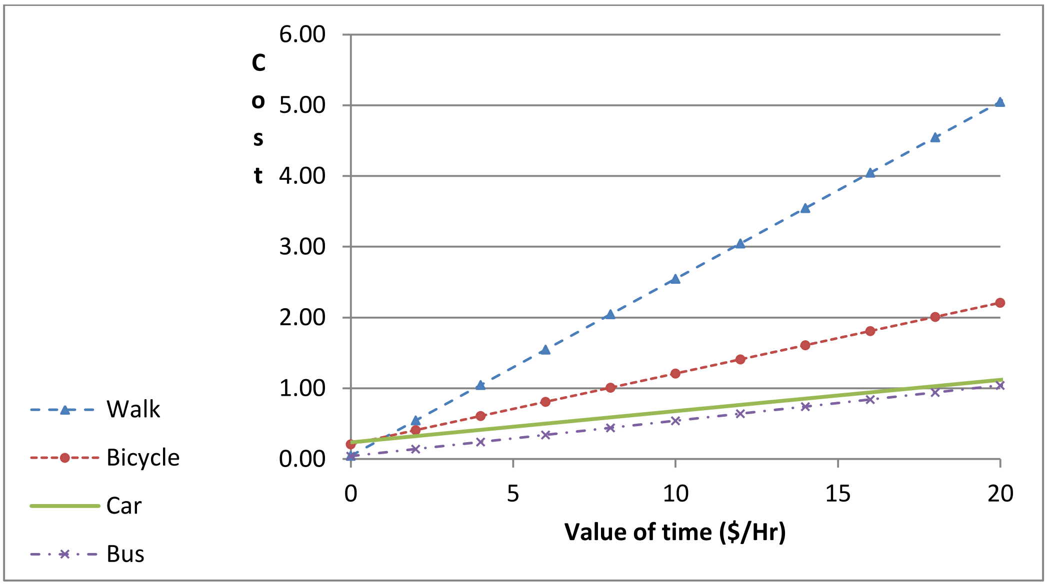

Figure 3: costs per passenger-km ($) by mode and value of time

Due to the concentration of lines for low values of VOT, an additional view of costs for VOT between zero and two dollars per hour is presents below.

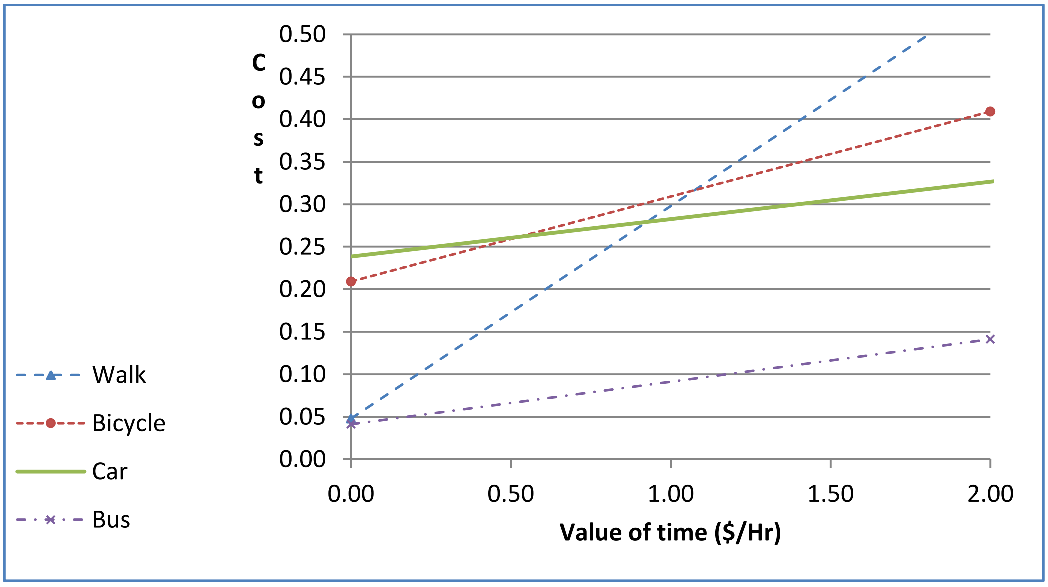

Figure 4: costs per passenger-km ($) by mode for low values of time

VOT

An increase in car price, within the margin between $US 6,000 and $US 25,000, has an impact on the per km-passenger cost. However, the change does not alter the order of costs between the different modes.

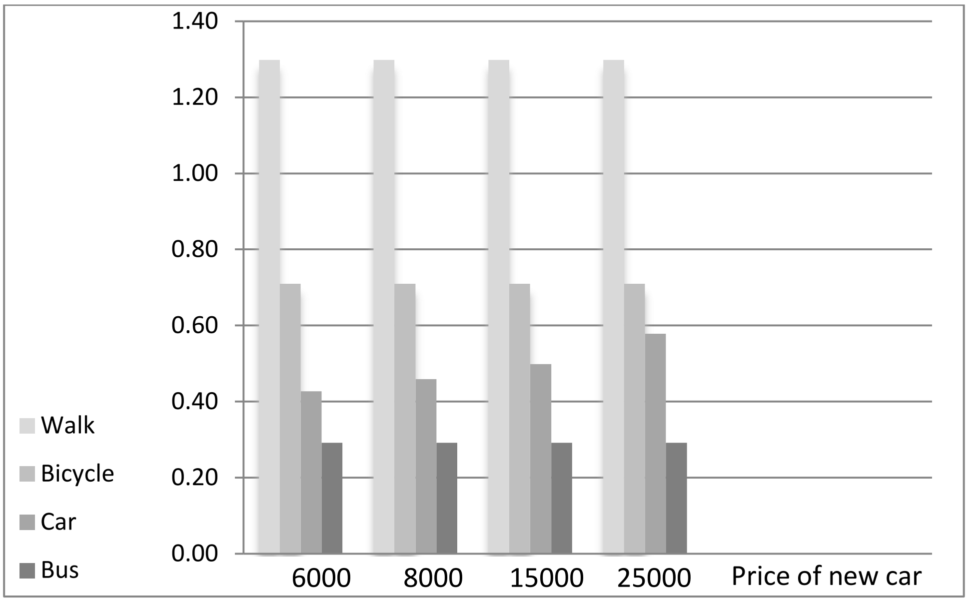

Figure 5: costs per passenger-km by mode and price of car

Some variables of motorized vehicles costs are expected to rise in the future. In particular – fuel costs. The following chart include a comparison between modes under the assumption of an increase of 300% percent in vehicle operating costs (fuel, maintenance, etc.). Under this assumption bicycles costs are almost equal to car costs.

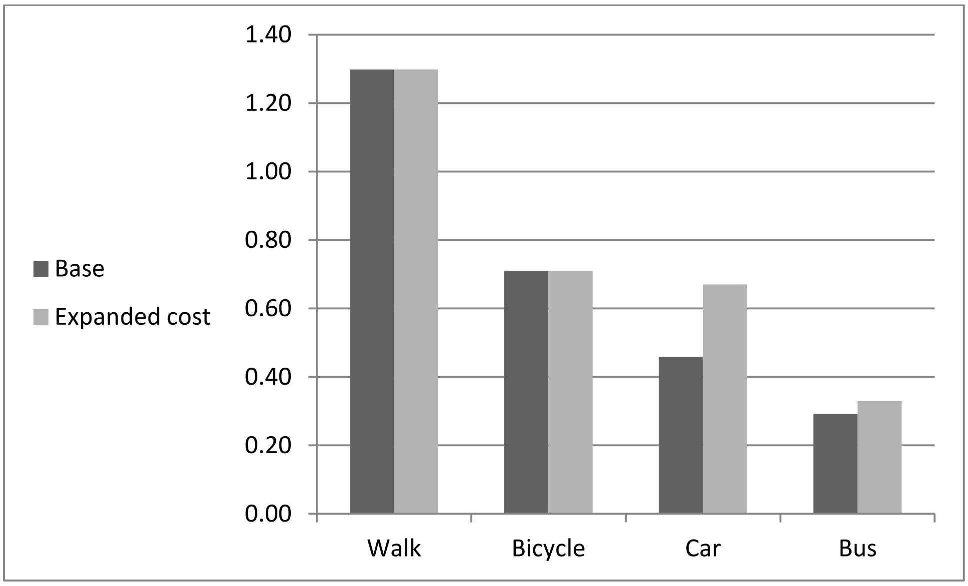

Figure 6: costs per passenger-km by mode when motorized vehicles variable costs increase in 300%.

CONCLUSIONS

The research was carried out using average conditions and average costs. Hence, the following conclusions should serve merely as guidelines. Local considerations must be applied before adopting these results.

- The sustainability of bicycle riding is questionable. Although bicycles are better from the environmental point of view, their safety problems raise doubt about their social state.
- An economic analysis shows that due to accidents costs, and in a reasonable range of the passenger's value of time, bicycles are inferior to car or bus.
- When the value of time is low, e.g. in leisure trips or in developing countries, bicycles may be found superior to car travel.
- The economic analysis shows that in a reasonable range of other variables, such as car and bus prices and vehicles operating costs (including fuel costs), bicycles are inferior to buses and cars, considering overall costs per passenger-km.
- Bicycles costs refer mainly to two items: low speed and high accidents costs. Hence, in congested urban areas, where routes are short and segregated bicycle lanes are available, the choice of bicycles should be more favorable.
- The economic break-even point indicates that under conditions in which bicycles ride in mixed traffic, bus travel is considerably superior to bike or to car. As well, in these conditions, car is economically superior to bicycle.

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