wctr'04
4-8 july 2004 / istanbul-turkey

REBUILDING A SIGNALISED INTERSECTION INTO A ROUNDABOUT: A SOCIAL COST BENEFIT ANALYSIS[1]

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Abstract

Every year 1,500 people die on the roads of Belgium. A large share of these accidents happens on intersections. The roundabout seems to be a solution to lower the number of accidents. In this article, we look at the effects of rebuilding a signalised intersection into a roundabout. We want to know if it is economical efficient to replace an existing signalised intersection by a roundabout, that is, we want to know if the benefits are larger than the costs. The conclusion of this article is that the transformation of a signalised intersection into a roundabout provides a net benefit to society. The transformation makes traffic smoother and safer. The benefits of this are larger than the increased environmental cost and the cost of rebuilding. A sensitivity analysis shows that the results are very robust for changes in accident-, time- and infrastructure costs.

Keywords: Transport; Cost-benefit analysis; Road infrastructure; Junctions
Topic Area: E1 Assessment and Appraisal Methods

1. Introduction

Traffic safety is an area of increased attention and awareness. In order to be able to conduct a good safety policy, a good evaluation of potential measures is necessary. One should consider all the benefits and costs of the measure and only implement them if their benefits are larger than their costs. In this paper we consider a concrete safety measure, which is very popular in Belgium nowadays. We make a social cost-benefit analysis of rebuilding a signalised intersection into a roundabout[3].

The structure of the paper is as follows. In this section we sketch the background of the problem and explain some concepts. Next we give an overview of studies which consider the effects of the rebuilding. In section 3 we present the analytical framework that we will use. Section 4 gives the actual analysis. Finally, section 5 concludes.

1.1. Background

In Belgium 150 people per million inhabitants die in traffic. This tragic number is magnified when we consider the corresponding larger number of serious and light injuries. Figures of the Belgian Institute for Traffic Safety (BIVV) (2001) show that in 1999 38.14 % of all injury accidents happened on junctions[4]. Because of the poor registration of traffic accidents these figures are incomplete. One estimates that the total number of accidents on

[1] Published in Dutch in Tijdschrift voor Economie en Management, Vol XLVII (4), December 2002, pp 577-605
[2] I would like to thank I. Mayeres and dr. prof. S. Proost for their comments and suggestions. I would like to acknowledge the financial support of the DWTC research program – Indicators for sustainable development – contract CP/01/38 (Economic Analysis of Traffic Safety: Theory and Applications)
[3] The same analysis can be made for the rebuilding of an 'uncontrolled' intersection. This is done in Delhaye (2001). In this article we analyse the signalised intersection because the possible benefits are larger. For studies (consider footnote 4) show that the accident risk and the waiting time decline more in the rebuilding of a signalised intersection than of an 'uncontrolled' intersection into a roundabout. Moreover it became clear that the discharge of pollutants and the fuel use increased with the rebuilding of an 'uncontrolled' junction.
[4] With the word junction we denote each crossing of two or more roads. Hence a junction can be an 'uncontrolled' intersection, a signalised intersection or a roundabout.

junctions, including accidents with only material damage lies between 150,000 en 250,000 per year. This figure has not changed in 15 years despite the many efforts to improve safety on intersections.

There are different theoretical reasons why roundabouts may improve safety on intersections. First of all, they decrease speed, which is an important factor in the causation and severity of accidents. Secondly, they do not allow frontal accidents and eliminate left turns in front of traffic. In general, by the change of the angle, the accidents that do happen are less serious. However, the rebuilding also has other consequences: it influences the time costs, pollution and the capacity of junctions.

Given that roundabouts may improve traffic safety, but taking into account all other effects, we want to know if it is economically efficient to replace a signalised intersection by a roundabout. Because of lack of data for Belgium, we rely on different studies from different countries. Note, however, that when there is data available for Belgium, the analysis is easily adapted. In section two we will describe the effects we use for the analysis.

1.2. Definitions

In this paper an intersection denotes every crossing of two or more roads. A 'signalised intersection' is an intersection where traffic lights in two or more phases rule the traffic. An 'uncontrolled intersection' is an intersection ruled by stop signs, priority signs or where there is right of way for traffic from the right. A roundabout is defined as an intersection for circular traffic with three features. First of all, following traffic legislation, traffic on the roundabout has the right of way. Secondly, the roundabout should have specific geometrical characteristics. There has to be a middle isle, a circular outer side, a canalising and marking of the supply roads. Thirdly, they should be signalized as roundabouts. With respect to the size, we can differentiate three types of roundabouts. In Belgium a roundabout with a diameter of 18-25 meter is called a mini roundabout. A roundabout with a diameter of 25-40 meter a compact roundabout and if the diameter is between 35 and 50 meter it is a large roundabout. Note that a large roundabout is considered as the succession of different T-crossings rather than as one intersection. In this paper we consider the compact roundabout since this type is the most common in Belgium. We can also categorize according to the number of lanes. We consider one lane roundabouts since these are more frequent in Belgium[5].

2. Consequences of rebuilding

Most studies[6] agree on the influences of rebuilding, although they can differ in the order of magnitude. They all show that the number of accidents and their severity decline. Most studies find a gain in time, although there is a difference for the main and the side road. For the other effects we only found a study by Hyden & Várhlyi (2000), which shows that the fuel use and the pollution declines.

Table 1 gives the exact values of the effects which we use in the analysis and the country from which the values are taken of.

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[5] Technologisch Instituut-K VIV, Genootschap Verkeerskunde (1995)

[6] Akçelik R., Chung E., Besley M. (1998), Cedersund H.-°A (1995), Centre d'Etudes des Transport Urbain, Service d'Etudes Techniques des Routes et Autoroutes (1993), Hyden C., Várhelyi A. (2000), Insurance institute for highway safety (2000), Ministerie van de Vlaamse Gemeenschap (1997), Ministère Wallon de l'Equipement et des transports Service d'Etudes Techniques des Routes et Autoroutes (1998 en 1999), Technologisch Instituut-K VIV, Genootschap Verkeerskunde (1995), Van Minnen J. (1989, 1993 en 1994). For an overview of the results of the different studies we refer to Delhaye (2001).

Table 1 : The effects of rebuilding

Effect	*'signalised intersection' → roundabout*	*Source*
Accidents[a]	#accidents/10 mio arriving vehicles: 3.35 → 1.24 #deaths/100 accidents: 10 → 6 #heavily injured/100 accidents: 45 → 33 #lightly injured/100 accidents: 126 → 106	Cetur (1993): Germany Setra (1998): France
Time	Waiting time: 10 sec → 0 Geometrical time[b]: Main road: 4.75 sec →12 sec Side road: 14 sec →12 sec	Setra (1998): France
Environment	CO ↓ with 29% NOx ↓ with 21% Other particles: 1 to 1 relation with fuel use	Hyden &Várhelyi (2000): Sweden
Fuel use	↓ with 25 %	Hyden &Várhelyi (2000): Sweden

a: Note that the figures concerning the severity of accidents are actually the figures for 'uncontrolled intersections'. Because we lack figures for the 'signalised intersections' we assume that the severity of accidents is the same for both types.

b: For the calculation of the geometrical time on an intersection we refer to IV.B.3.

This study checks if the decrease in accidents, pollution and fuel use outweighs the investment costs and the possible time loss.

3. Economic framework

The economic framework we use to determine if the rebuilding is economically efficient is based on De Borger & Proost (1997).

3.1. The current market equilibrium

For the current market equilibrium we look at the market for car trips in which one uses the intersection. Consider **Figure 1**.

First we look at the demand of vehicles for this trip. Transport is a derived demand. It is not undertaken for its own consumption value but as a mean. Demand is a function of many factors, but will obviously depend on the generalised prise (GP) of the trip. The generalised price is the sum of the resource cost, the marginal private time and accident cost and taxes. The resource cost (r) comprises the costs of the use of the car such as purchase price, insurance, maintenance and repair, etc. The marginal private time cost (mptc) equals the time spent on the journey, multiplied with the value of the time. The own accident costs (mpac) equal:

$$\sum_j (\text{accident risk}_j * \text{cost of accident j for the car driver})$$

with j equal to the different types of accidents. The private cost of an accident j for the car user consists of the loss of joy of life and the financial costs carried by the car user himself (for example part of the medical costs). Finally the generalised costs also comprise the taxes which are connected with driving. We assume that these taxes (t) are constant.

One expects that as the generalised price rises, the demand for trips declines. Other elements which determine the demand for this trip are the generalised price of car travel on other places, of public transport, income, etc. We assume that all these remain constant.

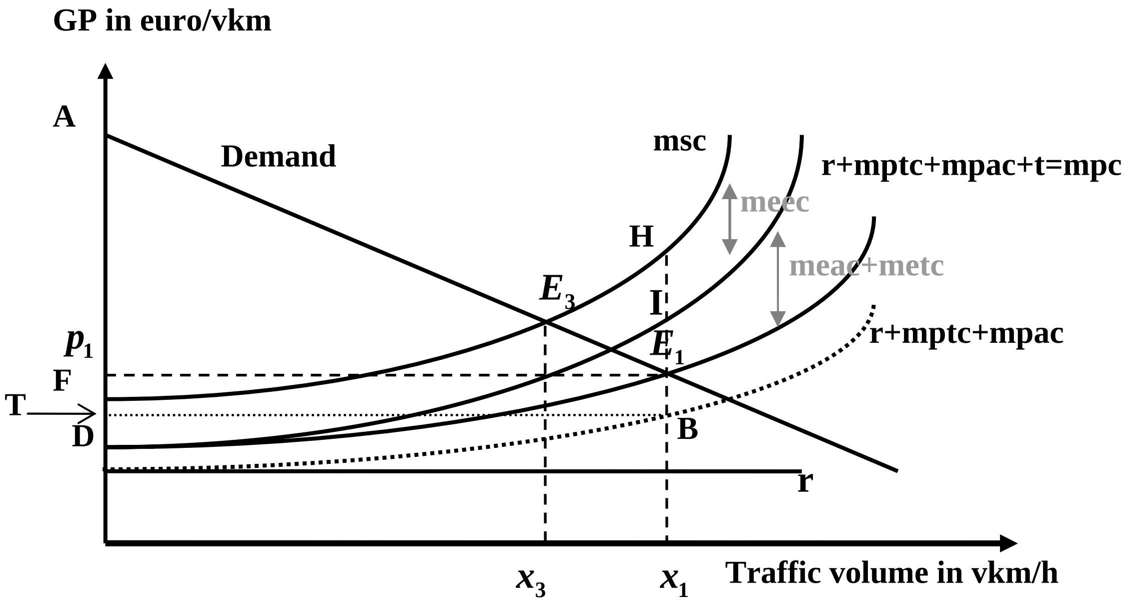

Figure 1 : Marginal external costs in equilibrium

On the supply side, we need to determine how the generalised cost depends on the traffic volume. The generalised cost also includes the resource cost and the marginal private time and accident cost. In order not to complicate the analysis we assume that the resource cost is independent of the volume. The marginal private time cost is an increasing function of the traffic volume. Indeed, the average speed of traffic flow will drop as more drivers come onto the road. The relation of the marginal private accident costs with the traffic volume is not clear cut. If there is more traffic one might expect that the number of accidents increases since the number of confrontations increases. On the other hand, the speed will decrease if there is more traffic; hence the severity of the accidents decreases. People may also drive more careful if there is more traffic.

The resource cost, the private accident costs and the private time cost together with the taxes determine the marginal private cost for the consumer (MPC). This cost consists of all monetary costs, time costs and accident cost which the traveller takes into account. On **Figure 1** the current market equilibrium is E_1, the point at which the demand intersects the marginal private costs. The generalised price is P_1.

However, in a cost-benefit analysis we consider the society as a whole. Transport brings about a number of unwanted side effects such as congestion, air pollution, noise pollution, accidents... These are called negative external effects. External because the user does not take them into account. Negative because they impose a cost on society. These external costs are an increasing function of the traffic volume. The marginal costs for society (MSC) consist of the marginal private costs, the marginal external time costs, the marginal external accident costs and the marginal external environmental costs. The marginal external time costs (METC) are the extra time costs an additional road user imposes upon all other road users. The marginal external accident cost (MEAC) is the effect of an additional user on the private accident costs of the other road users. This is partly covered by the insurance if the insurance is not considered fixed and in so far as the insurance covers all accident costs. The two remaining marginal external costs are presented together on **Figure 1** as MEEC. The first element is the accident costs for the rest of the society. The second element is the marginal external environmental cost. This captures pollution, noise nuisance, etc. The car user does not take these external effects into account and hence the equilibrium E_1 is an equilibrium with more traffic than optimal for society. In E_1 the marginal private willingness to pay does not equal the marginal social costs, but the marginal private costs. Total welfare of this equilibrium can be represented in two similar ways. Firstly, one can measure total welfare as the sum of the consumer surplus, the producer surplus and the net tax revenues, minus the external costs. The consumer surplus equals the difference in the willingness to pay, which is represented by the demand and real expenditures. In terms of **Figure 1** the consumer surplus is represented by the area A-P_1-E_1. The producer surplus equals zero in this setting[7]. The tax revenues are simply equal to the tax per unit times quantities and are represented by the area P_1-E_1-B-T. The external costs D-F-H-I[8] have to be subtracted from the sum of the consumer surplus and the tax revenues. This is equivalent to a second graphical representation of total welfare. It is the difference between the total willingness to pay and the total social cost. Graphically welfare can then be represented as the area F-A-E_3 minus the area E_1-E_3-H. The area E_1-E_3-H equals the possible gain in welfare if all car users would pay the social optimal price. We will use the first approximation.

3.2. The replacement of a signalised intersection by a roundabout

We now show the effect of replacing a signalised intersection by a roundabout graphically. From paragraph II we know that the replacement of a signalised intersection caused a decrease in the accident risk and hence in the internal and external accident cost, that the fuel use and hence the resource cost and the tax revenues from transport decrease and that the environmental cost decreases. The effect on the time is not clear-cut. In other words, the generalised price to drive over the intersection decreases because of the rebuilding. This causes a decrease in the price of the total trip. Note, however, that the distance driven on the intersection is relatively small compared with the total trip. Hence the decrease of the generalised price on the intersection will not have an enormous effect on the generalised price of the trip. For we assume that the generalised price on the remainder of the road does not change[9]. In order to construct the roundabout, the government has to raise an additional tax. We assume that the income tax increases. Figure 2[10] shows the effects of replacing a signalised intersection by a roundabout.

The generalised price decreases from P_1 to P_2. As a consequence the demand will increase[11] from X_1 to X_2.

The net effect on welfare can be seen by calculating the difference in total welfare in the two equilibriums:

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[7] The producer surplus consists of two components. Firstly, there is the surplus for the producers of the purchased goods; this is the profits of the suppliers of cars, tyres, fuel, etc. We assume perfect competition and constant production costs r per kilometre, so there is no economic profit. Hence this surplus equals zero. The second component comprises the time cost of the car user. In fact, he 'produces' vehicle kilometres by supplying his own time. In their dual role of consumer-producer they 'pay' their own time cost. However, because he pays exactly the average time cost, this second surplus also equals zero.

[8] The external costs equal D-F-H-E_1. However if we would subtract this, we would be double counting. For in our calculation of the consumer surplus we already take into account the total cost of time. This total cost of time comprises the private and the external cost of time. Hence we already take into account the external time costs. This is the same for part of the accident costs. Hence we can only subtract the area D-F-H-I.

[9] We assume that the additional users do not influence the time cost and the accident risk on the remainder of the road. This assumption is made because of practical reasons. Note that in reality a change on one point can affect the remainder of the stretch. It is possible that traffic is smoother on the roundabout but less smooth somewhere else in the trip. This means that we overestimate the benefits of the rebuilding on time, environment and fuel use. The effect on accidents is not clear. The precise effects depend on the network and taking them into account would complicate the analysis too much.

[10] Note that this figure is slightly different from **Figure 1**. For reasons of clarity we did not take up the METC and the MEAC.

[11] Note that for reasons of clarity we exaggerated the magnitude of the shifts.

net benefit/cost = $\Delta CS+\Delta PS+(1+\lambda)\Delta TR+\Delta EXT$

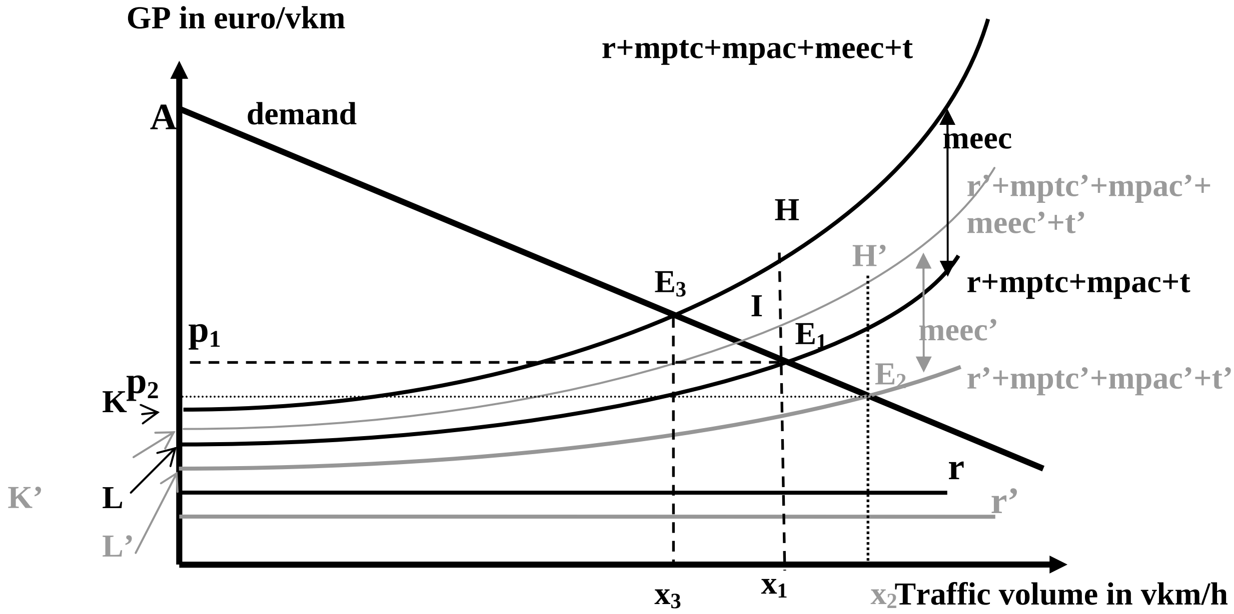

Figure 2 : The effect of replacing a signalised intersection by a roundabout

The first element equals the change in consumer surplus and is represented in Figure 2 by the area P_1-P_2-E_1-E_2. In other words, we consider the difference between the two alternatives in resource cost, time cost and private accident cost for existing as well as for new users. The difference in producer surplus equals zero in this exercise, given that the producer surplus before and after equal zero. The third element, which is not represented in **Figure 2**, has to do with the fact that the construction of roundabouts happens with tax revenue (TR). We have to take into account the investment itself and possibly the difference in maintenance costs. Moreover because of the effect on fuel use and the increase in demand there will also be an effect on the tax revenues from transport. These taxes will cost more to society than the amount needed since levying taxes causes distortions. This is why we multiply with $(1+\lambda)$, the marginal cost of public funds. What is this marginal cost of public funds? Taxes cause distortions in the economy. For families, every euro paid to taxes means a direct cost, but there is also a loss because of the less efficient functioning of the economy. Indeed, when taxes move resources from the tax payer to the government, at the same time decisions of the consumer about the use of the other means, such as time and money, are influenced. The measure for this hidden cost of raising the taxes is the marginal cost of public funds[12]. In other words, it costs $(1+\lambda)$ euro to collect 1 euro. The fourth element is the change in external costs for the society. In Figure 2 this is represented by H-E_1-L-K minus H'-E_2-L'-K'.

If this sum is greater than zero, we have a net benefit and it is economically efficient to construct roundabouts. If the sum is negative, it is better to use the money for something else.

[12] Van De Voorde (1987).

4. The replacement of a signalised intersection by a roundabout

In this paragraph we discuss the actual cost-benefit analysis. We consider the effects for one year and discuss the consequences of replacing a signalised intersection by a roundabout. All figures are in euro (2000)[13]. We start with a number of assumptions. Next, we give the calculation of the generalised price and the change in demand. We conclude with the actual cost-benefit analysis.

4.1. Cost-benefit analysis: assumptions

In order to be able to perform this cost-benefit analysis we have to make a number of assumptions.

Firstly, we only consider, as mentioned before, the compact roundabout with one lane, since this is the most frequent kind in Belgium. We consider a roundabout with four branches and assume measures such as given in **Figure 3**.

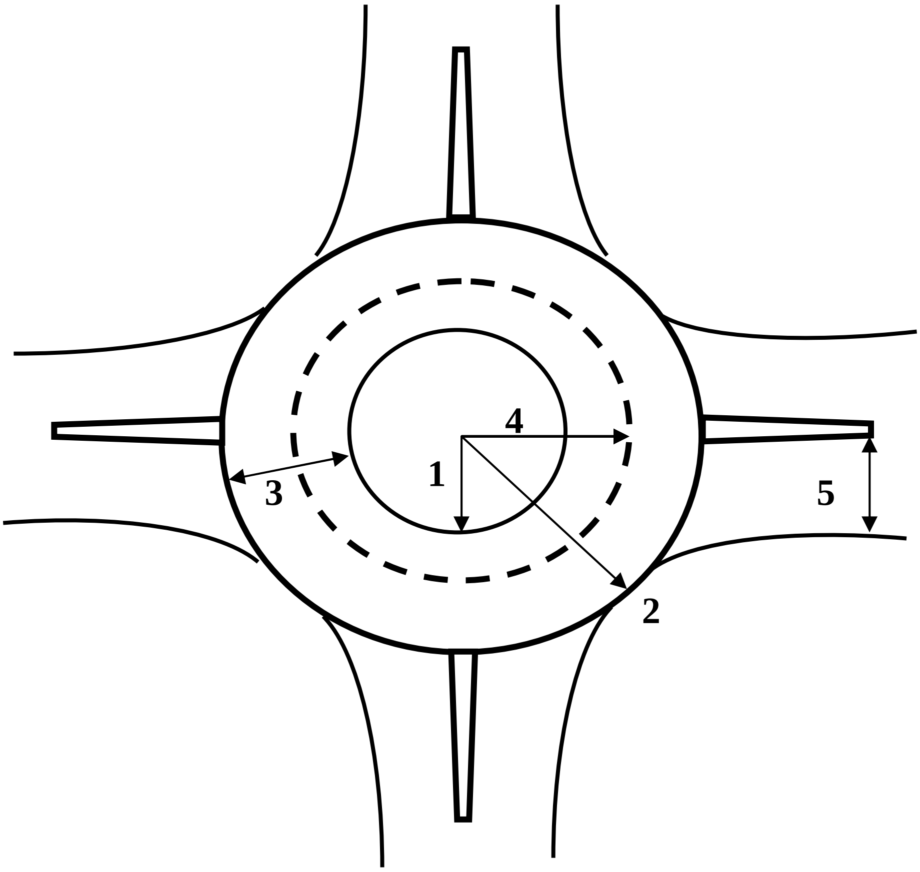

Figure 3 : Design of the assumed roundabout

With

1 = Bi, the radius of the inner circle = 10.5 meter
2 = Bu, the radius of the outer circle = 16 meter
3 = the width of the road = 5.5 meter
4 = the radius of the circle, which divides the road into half = 13.25 meter

[13] European Commission (2000), NBB (2001).

5 = R, the width of the road of the branches = 3 meter

Secondly, we assume that traffic on the side road equals 30% of the traffic on the main road. We also assume that half of the cars drive straight ahead and that one fourth turns to the right and one fourth turns to the left.

Thirdly, we assume[14] that during the peak hours on average 750 car-units (CU) approach the roundabout/intersection from the main road. This means that 23.1% of these 750 CU[15], this is 173.25 CU, approach the intersection from the side roads. This gives an average of 461.63 CU per branch. We assume that the peak counts for 12% of the daily traffic. This leads to 3,846.88 CU/day/branch. We multiply with 4 and assume that yearly traffic equals 300 times the daily traffic. This leads to 4,616,250 CU per year per intersection before the reconstruction.

Furthermore we assume an occupation rate of 1.2 persons on average per vehicle.

Because environmental effects differ between gasoline and diesel cars we categorize cars according to their fuel type. In Belgium the share of gasoline cars is 59.4 %, the share of diesel cars equals 40.6 %. We assume that these shares are also reflected in the traffic on the intersection. Note that the environmental effects differ between vehicles and trucks. We do not consider this since we do not know the share of trucks on the intersection. Intuitively we can state that if the roundabout is large enough the same effects play as with vehicles. The time, environmental and fuel costs will decline. However, the value of the decline in time will be larger, for the time cost of truck drivers is higher. The effect on accidents is not clear. The cost of construction that we use is an average cost for an average composition of traffic. The cost of maintenance probably increases with the share of the trucks. For trucks cause more damage to the road surface and as will be clear later on, the road surface is larger on a roundabout than on a crossing with traffic lights.

For the fuel prices we use the average fuel prices for the fiscal year 2000 as calculated by the price service of the Ministry of Economic Business (2001).

For the sake of simplicity we assume that the new users did not travel before[16]. If among the new users some people took a different road before, the rebuilding also has an effect on the other roads.

Finally, note that in our calculation we do not take everything into account. We do not take into account the loss in time, drivers face during the rebuilding. It is practically impossible to calculate average additional distances and additional time needed because of diversions. Secondly, note that studies show that in the months close after the rebuilding, the number of accidents increases. People seem to adapt rather slowly to changed conditions. We assume that the accident risk is constant over time. Thirdly, we do not consider bicyclists and pedestrians. The study of Van Minnen (1993) shows that the number of accidents with bicyclists and pedestrians decrease, but not as much as the decrease for the occupants of the vehicles. Factors one and two make that we overestimate the benefits of the rebuilding. The third factor leads to an underestimation.

4.2. Change in demand

From Figure 2 it was clear that the generalised price decreases because of the rebuilding. Because of the decrease in the price, traffic increases. In order to know the change in demand, we need to calculate the change in generalised price. The generalized price per trip equals (the number of km on the intersection*generalised price per km on the intersection) + (the number of km on the remainder of the trip*generalised price per km on the rest of the road).

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[14] Ministère Wallon de l'Equipement et des transports, direction générale des autoroutes et des routes (1992).
[15] Remember the second assumption: the traffic on the side roads equals 30 % of the traffic on the main road.
[16] For a change of this assumption we refer to the sensitivity analysis.

1. Km per vehicle

We assume[17] that vehicles drive in the middle of the road and hence drive on an imaginary circle with a radius of 13.25 metre. The circumference of the circle then equals 83.25 metre. We assume that on average half of this distance is covered[18], this is 41.63 metre. For the sake of simplicity we assume that the covered distance on the crossing is on average the same as on the roundabout.

The average trip length in Belgium is 13 kilometres. The number of kilometres on the remainder of the road then equals 12.96 kilometres.

2. Fuel and vehicle costs per kilometre

The prices and the fuel consumption differ between gasoline and petrol cars. This is why we first calculate the fuel prices (net of taxes) per kilometre by multiplying the price and the consumption. Next, we multiply with the respective shares to obtain one weighted price. We do this for the signalised intersection, the roundabout and the remainder of the road. Note that the reconstruction affects the fuel consumption. Because one has to stop and start less, the average fuel consumption declines with on average 25% (Hyden & Várhlyi, 2000). We assume that the decline is the same for gasoline and diesel cars. We obtain a fuel price of 0.03 euro/km on the signalised intersection and on the remainder of the road[19] and 0.02 euro/km on the roundabout.

For the vehicle costs per year we use data from De Borger & Proost (1997). These costs consist of the annuity of the purchase costs, the traffic tax, the insurance, the radio taxes, repairs, battery costs, the costs of tyres and oil. We remove the taxes[20] and find, using the respective shares of gasoline and diesel cars, a weighted average vehicle cost per km of 0.21 euro. The replacement of a signalised intersection by a roundabout does not affect the vehicle costs.

3. Time cost per vehicle

We need to distinguish waiting time from geometrical time. Waiting time is for example the time that people wait for the red lights, the time that one is waiting in the row and the time needed to turn left. In other words it is the time loss caused by traffic or by lights. A study of Setra (1998) shows that the average waiting time on a 'controlled' crossing is around 10 seconds. On a roundabout the waiting time is the time that one has to wait before one can ride up the roundabout. We assume that the maximum capacity of the roundabout is not reached and hence that the waiting time is around zero seconds[21]. Note that this is not a realistic assumption in peak traffic. Geometrical time is the time needed to cross the signalised intersection/roundabout. For the signalised intersection we need to distinguish the main from the side roads. A car on the main road will have a higher probability to drive straight ahead and hence will be faster on his destination than a car on the side road. For the calculation of the geometrical time we use the data from Setra (1998). After adjusting for the different shares of driving direction (1/2,1/4,1/4) we obtain a weighted average geometrical time on the main road of 4.75 seconds and 14 seconds on the side roads. Because we assume that traffic on the side road equals 30% of traffic on main roads, we multiply the geometrical time on the side roads (main road) with 23.1 % (76.9 %). The average geometrical time on a roundabout equals 12 seconds for passenger vehicles. The total time needed to cross the signalised intersection equals 10 sec + (0.231*14 sec +0.769*4.75 sec) or 16.89 seconds. The total time needed to cross the roundabout equals the geometrical time, or 12 seconds, since we assume that there is not

[17] See **Figure 3**.
[18] See the assumptions on the shares of the directions: 1/2, 1/4, 1/4.
[19] Note that the price on the road and the signalised intersection are equal because of rounding off.
[20] We assume an average tax rate of 21 %.
[21] This assumption is not very strict. One can also consider this as a normalization. Important for the analysis is that the difference in waiting time equals 10 seconds.

waiting time. We assume that on the remainder of the road, the average speed equals 31.1 km/h[22]. Hence one needs 1500 seconds to cover the remaining 12.96 kilometres.

In order to obtain the time cost per vehicle we need to multiply these values with the value of time per vehicle. We use the results of Gunn et al (1997) to calculate the value of time per vehicle. They calculate the value of time for different trip purposes using 'stated preferences'. We multiply these values with the respective shares of the trip purposes[23] to obtain an average money value per hour. We get an average value per hour of 9.29 euro for peak travel and 8.58 euro for off-peak travel. If we assume that the peak counts for 12% of all traffic and that, on average, the occupancy rate per car is 1.2 persons, we obtain an average value of time of 10.44 euro/vehicle/hour or 0.0029 euro/vehicle/second. The time costs that we then obtain are expressed in Table 2.

Table 2 : Time cost per vehicle

	Signalised intersection	*Roundabout*	*Remainder of the trip*
time(sec/vehicle)	16.89	12	1,500
value of time (€ /sec)	0.0029	0.0029	0.0029
Time cost/vehicle (€ /vehicle)	0.05	0.03	4.35

Source: Setra (1998), own calculations.

Because of the rebuilding the time needed to cross the intersection declines, and hence the time cost per vehicle declines.

4. Marginal private accident cost per vehicle

Accident costs can be divided into costs, which are already expressed in monetary terms and those, which are not. In the first group we find, among others, damages to property and vehicles, medical expenses, costs for the ambulance and the police. Somewhat more reluctant we can say that also the net loss in production, caused by the fact that the victim cannot work anymore, belongs to this group. For we can approximate this by his gross wages minus his consumption. However it is much more difficult to value pain, discomfort and suffering caused by injury and death. We note that in deciding whether to participate in traffic, the user partly takes into account that he might have an accident in which he can be killed, injured and/or have material damage. Hence, part of the accident cost is internalised and is consequently considered as a private cost. In Figure 2 this was denoted by mpac. However, there are also external costs, such as the influence an additional road user has on the accident risks for the other users. Moreover, in case of an accident not all costs are paid by the victim. Part of the accident costs are paid by society.

We define the marginal private accident cost per vehicle as in paragraph three as follows:

$$\text{Marginal private accidentcost per vehicle} = \sum_j (\text{accident risk}_j * \text{own willingness to pay}_j)$$

with j, the different accident types.

Note that we only take into account the private costs, in other words the costs which people take into account. We approximate these costs by the 'human costs' of Schwab (1995). These values are obtained by using the 'stated preferences' method. The other costs (rehabilitation costs, loss in production, medical and administrative costs) are considered external. The value of an accident with serious injuries is approximated by

[22] BIVV (2001).
[23] Stratec (1992).

accidents which cause disability. Given the definition of an accident with serious injuries this figure will be an overestimation of the value of being seriously injured.

Table 3 : Valuation of accident

Accident costs	*Fatal accident*	*If handicap*	*Light injury*
Human costs (€)	1,099,103	899,416	95,311
Total other costs (€)	1,004,861	459,413	5,717
Total costs (€)	**2,103,964**	**1,358,830**	**101,028**

Source: Schwab (1995).

For the calculation of the accident risks we use German and French data (

Table 1). Note that the probability of an accident is smaller on a roundabout than on a signalised intersection (1.24 versus 3.35 per 10 million vehicles). Also note that the consequences of an accident are less serious on a roundabout. We combine the own willingness to pay with the accident risk and obtain the marginal private accident cost as expressed in Table 4.

Table 4 : Marginal private accident cost

	Signalised intersection			*Roundabout*			*Remainder of Trip*[a]		
	Risk #victims/vehicle	*WTP €/victim*	*Mpac €/vehicle*	*Risk #victims/vehicle*	*WTP €/victim*	*Mpac €/vehicle*	*Risk #victims/vehicle*	*WTP €/victim*	*Mpac €/vehicle*
Fatal	3.35E-08	1,099,103	0.04	7.44E-09	1,099,103	0.01	2.19E-07	1,099,103	0.24
Heavily injured	1.51E-07	899,426	0.14	4.09E-08	899,426	0.04	1.24E-06	899,426	1.11
Lightly injured	4.22E-07	95,311	0.04	1.31E-07	95,311	0.01	2.22E-05	95,311	2.11
Sum €/vehicle			**0.21**			**0.06**			**3.47**

a: the accident risk on the remainder of the trip is the accident risk over 12.96 km.
Source: Schwab (1995), own calculations.

From Table 4 it is clear that the private accident cost is much lower on the roundabout.

5. Taxes.

We assume a tax of 21 % on the resource cost and obtain a tax cost of 0.04 euro per km. For the fuel taxes we multiply the fuel consumption with the taxes on gasoline and diesel. Next we calculate the weighted average taking into account the fuel shares and obtain a fuel tax of 0.05 euro/km on the signalised intersection, 0.03 euro/km on the roundabout and 0.05 euro/km on the remainder of the trip.

6. The generalised price and the new demand.

Table 5 : Generalised price per vehicle

	Signalised intersection	*Roundabout*	*Road*
Resource cost (€/vehicle)	0.007	0.007	2.23
Time cost (€/vehicle)	0.05	0.03	4.35
Mpac (€/vehicle)	0.21	0.06	3.47

Taxes (€/vehicle)	0.003	0.003	1.07
Generalised price (€/vehicle)	**0.27**	**0.10**	**11.49**

Source: own calculations.

Table 5 summarizes the impact on the generalized price. We see that the rebuilding of the intersection more than halves the generalised price. The most important factor is the decrease in mpac. The generalised price of the trip equals 11.76 before and 11.59 euro after the rebuilding. Given a price elasticity of –0.5 we can calculate the increase in demand. The demand for the trip will increase with 33.371 car-units and in the situation after the rebuilding there will be 4.649.621 car-units driving on the roundabout[24].

4.3. Cost-benefit analysis for one year

1. Consumer surplus

We denoted the change in consumer surplus on Figure 2 by the area $(P_1-P_2)*X_1$ for the existing users and the triangle $(P_1-P_2)*(X_2-X_1)/2$ for the new users. Using X_1, X_2, P_1 and P_2 we calculate the two areas. We obtain a gain in consumer surplus of 781,141.69 euro for the existing users and 2,837.94 euro for the new users. This consumer surplus consists of the gains in time, in private accident cost and in fuel use.

2. Government

a. Taxes

We assumed that the resource cost was unaffected by the rebuilding. Hence the tax revenues on the resource cost stay constant for the existing users. However, the new users make that the revenues rise with 15,672.50 euro.

With respect to the fuel taxes we multiply the difference in use for the existing users with the taxes and with X_1. We obtain a loss of 2,211.53 euro. However, there are also new users. They generate an additional revenue of 35,079.93 euro.

Hence the rebuilding raises the tax revenues of the state with 48,540.89 euro.

b. Investment cost and maintenance

The exact cost of rebuilding are hard to calculate since the budgets used for constructing roundabouts often also incorporate other items, such as the reconstruction of roads near the roundabout. Hence the cost of a roundabout varies between 123,946.76 euro and 1,239,467.62 euro. We only consider the costs of rebuilding a signalised intersection into a roundabout. We assume that because of the limited diameter of modern roundabouts there are no expropriations. We use the costs stated by the Flemish Community (1997). The costs of rebuilding a signalised intersection into a roundabout then equals 467,136 euro. However a roundabout has its use for more than one year, hence we only have to take into account the cost for one year. Assuming a life expectancy of 10 years and a discount rate of 5 % we obtain an annuity of –60,456 euro.

For calculating the costs of maintenance we take the difference in area and multiply this with the cost of maintenance. For the roundabout we also have to take into account the cost of maintenance of the inner circle. However, an advantage of a roundabout is that there are no lights which need maintenance or which can get defect. For the difference in maintenance we consider the difference in square kilometres for the 'black' (the road), the 'green' (the plants on the middle island) and the electric appliances. For the last element we only consider the fact that a roundabout does not have three-coloured lights. We do not consider the difference in yellow cones and traffic signs and assume that these costs are equal. For the maintenance of the green we multiply the area of the inner island with the cost of mowing the lawn[25]. We assume that this is done twice a year. We obtain a cost of

[24] For the exercise in which the number of car-units stays constant we refer to the sensitivity analysis.
[25] The cost of mowing the lawn equals 0.62 euro/m². Source: Flemish Community: P. De Backer (2001), personal communication.

429.49 euro. For the difference in maintenance of the road we multiply the difference in area between the signalised intersection and the roundabout with the average cost of maintenance[26]. The road surface of the signalised intersection equals $(2R)*(2R)+4*(Bu-R)*(2R)$. The corresponding road surface of the roundabout equals $2*\Pi*(Bu^2-Bi^2)$ with R, BU and Bi as described in Figure **3**. We obtain a cost of 90.84 euro. For the maintenance of the traffic lights we consider the energy cost per year. This equals 1,735 euro. In sum, we obtain a profit in maintenance of 1,214.67 euro. This is caused by the high operating costs of traffic lights.

Note that the investment and the maintenance are financed by taxes on labour, of which the marginal cost of public funds equals 1.2.

3. External costs

a. Accidents

(1) Existing users

Given the decrease in accident risk, the roundabout decreases the number of traffic accidents. We see a decline for all types of accidents. Hence the roundabout causes a benefit for society. We have to value the difference in accident risk using the costs for society. We use the values obtained by Schwab (1995). We multiply the difference in accident risk with their respective monetary values and obtain a monetary value per vehicle. Next, we multiply with the existing number of car-vehicles.

Table 6 : Effect on the external accident cost for the existing users

	Difference in accident risk (per vehicle)	*External cost (€/vehicle)*	*Monetary (€)*
Fatal	2.61E-08	1,004,861	0.0262
Heavily injured	1.10E-07	459,413	0.0505
Lightly injured	2.91E-07	5,717	$1.6636*10^{-3}$
Total/vehicle			0.07836
Total/intersection			361,478.74

Source: Schwab N., Soguel N. (1995), NBB (2001), European commission (2000), own calculations.

As is evident from

Table **6** the effect of rebuilding on accident for existing car users causes a monetary benefit of 361,478.74 euro. Note that the effect on the number of heavily injured dominates. The relative high valuation and the high occurrence of accidents with heavily injured play an important role in this. Note, however, that there are more single-vehicle accidents and accidents with only material damage on a roundabout. Given that these are less reported, there will be an underestimation of the number of accidents and the number of light injuries on a roundabout. Hence we overestimate the benefits of the roundabout. However, we cannot determine the magnitude of the fault.

(2) New users

The new users take into account the new accident risk. However they do not take into account the increased accident risk they cause on the rest of society. Hence we need the multiply the number of new road users with the new accident risk and with the costs for society. The results are expressed in **Table 7**.

[26] The cost of maintenance of the road surface equals 0,16 euro/m². Source: Flemish Community: P. De Backer (2001), personal communication.

Because of the new users the accident benefit of roundabouts decreases. If we subtract the costs of the new users from the benefit for the existing users we obtain a net benefit of 330,012.85 euro.

b. Environmental effects

According to

Table 1 the rebuilding of a signalised intersection into a roundabout also affects the discharge and hence the environment and our health. This change has to be valued since we attach value to both the environment as to our health. Traffic affects both of them. The rebuilding increased the discharges on the main road but decreased them on the side road. On average the discharge of CO of existing road users decreases with 29 % and the discharge of NOx with 21 %[27]. There will also be an effect on the other pollutants, but we do not have data for them. We assume that there is also a decrease in those pollutants, proportional to the decrease in fuel use. For there exist a 1 to 1 relationship between discharge and fuel use, given the same technology for many of these pollutants.

Table 7: Effect on the external accident costs for the new users

	Risk trip/vehicle (roundabout+road)	*External cost (€/vehicle)*	*Monetary (€)*
Fatal	2.26E-07	1,004,861	0.23
Heavily injured	1.28E-06	459,413	0.59
Lightly injured	2.23E-05	5,717	0.13
Total/vehicle			0.94
Total/intersection			31,466.89

Source: Schwab (1995), Setra (1998), Cetur (1993), own calculations.

(1) Valuation of air pollution

We use the values stated by Proost & Van Dender (1998), based on Extern-E. Because the discharge is different for diesel and gasoline cars we need to consider them separately. We use the earlier made assumption on their shares in traffic. Note however that there is also a difference for large and small vehicles and between peak and off-peak. We do not take this into account. For the discharge we assume constant technology.

(2) Existing users

We know the discharge per kilometre, but we only need the discharge over the distance driven on the signalised intersection/roundabout for the existing users. We assume as before that the average distance on the junction and roundabout are the same and equal to 41.63 meter. After calculating the discharge on the intersection, we consider the decline in discharge and multiply this with the respective monetary valuations. We then obtain a monetary value per vehicle, which we multiply with the number of victims. We do this for both fuel types. **Table 8** gives the results for the existing users.

Table 8 : Effect on the environmental costs for the existing users

	NOx	*CO*	*CO2*	*VOC*	*PM*	*Sox*	*Total*
Gasoline (€)	26.67	0.22	185.80	5.09	94.32	10.37	284.85
Diesel (€)	50.70	0.04	104.76	2.54	701.1	36.74	791.38

[27] Hyden C., Várhelyi A. (2000).

Total contribution (€)		1,076.23

Source: own calculations.

From **Table 8** it is clear that the largest contributions come from the decrease in CO2 and PM and to a lesser account the decline in NOx. However, what is really remarkable is the relative large contribution of PM for diesel cars. The decline in PM generated by the diesel cars is more important than the total contribution of gasoline cars. Hence if we compare the two types we see immediately that the contribution of diesel cars is much larger than those of gasoline cars. The reason for this is that diesel cars are much more pollutant than gasoline cars. They mainly discharge much more PM, which has a very high valuation, which on his turn has to do with the very damaging effects of PM.

(3) New users

However there are also new users and they cause additional pollution. For them we have to differentiate the road from the intersection. The calculations are as before. **Table 9** summarizes the additional environmental costs.

Table 9 : Effect on the environmental costs for the new users.

	Roundabout	*Road*	*Total (€)*
Gasoline (€)	-6.31	-2,604.34	-2,610.65
Diesel (€)	-17.41	-7,200.58	-7,217.99
Total contribution (€)			-9,828.64

Source: own calculations.

Note that the new users cause an environmental cost of 9,828.64 euro. Combined with the benefit for the existing users we get a net loss of -8,752.41 euro.

4. Total monetary value of replacing a signalised intersection by a roundabout

Table 10 summarizes all costs and benefits for one year. By making the sum we obtain the final cost or benefit of the rebuilding.

Table 10 : Total monetary effect of replacing a signalised intersection by a roundabout per year

Consumer surplus (€)		787,980
The Government (€)	Tax revenues	48,541
	Investment costs	-60,456
	Difference in maintenance	1,215
	MCPF[28]	-2,140
External costs (€)	Accidents	330,013
	Environment	-8,752
Total (€)		1,096,400

Source: own calculations.

Notice that the rebuilding of a ‘controlled’ junction into a roundabout causes a social benefit. The largest contribution is attributed to the positive effects on the external accident

[28] We already mentioned that it costs more than 1 euro to collect 1 euro in taxes. There is an additional cost, λ . Because of the rebuilding there is an investment cost, a difference in maintenance and a loss in tax revenues from fuels. In total there is a loss of 10,700 euro. However this loss has an additional cost of 2,140 euro.

cost and the consumer surplus. Within the consumer surplus the private accident cost is the most important element.

5. Sensitivity analysis

In order to make this analysis we made a lot of assumptions. We perform a sensitivity analysis to see how robust the results are. **Table 11** gives the final total benefits for society of the rebuilding given a number of changes in the base assumptions.

Table 11 : Sensitivity analysis

Change in assumption	*Total welfare*
Marginal external accident cost = 0	766,387
Own willingness to pay = 0	360,376
MEAC = 0 and WTP = 0	2,923
Value time = 0	1,041,054
Investment cost 16.11291 higher	0
If all traffic on side roads	1,194,689
If all traffic on main roads	1,066,889
If only gasoline cars	1,111,959
If only diesel cars	1,072,153
If no change in demand	1,073,953
If all new users come from different roads	1,079,393

Source: own calculations

Note that we obtain a benefit for society in each of the cases. Even if the meac and the willingness to pay equal zero we obtain a benefit, in other words, even if the accident risk stays constant, we still obtain a benefit. Also notice that the most important effects on the benefit are due to changes in assumptions with respect to accidents. This points to the importance of the consequences on accident risk because of the rebuilding. If the investment cost is 16 times higher, social welfare does not change due to the rebuilding. If the cost is smaller than 16 times the investment cost, ceteribus paribus, we obtain a benefit; if the cost is higher we obtain a loss.

Notice that when the demand for transport stays constant the result does not change drastically. With respect to the original analysis, the gain in consumer surplus is lower, the tax revenues become negative and the MCPF becomes more negative. On the other hand we find that the gain in accidents and environment is larger. With respect to the environment, we now even obtain a benefit in stead of a cost.

If we assume that the ‘new’ users are people which change stretch this does not change the result dramatically. We assume that the conditions on the old stretch are similar to the conditions on the new stretch before the rebuilding takes place. Because of this assumption the changes in time, accident risk, environment and fuel use are the same as for the existing users. Hence we can sum the existing and the ‘new’ users and multiply with the difference in time, accidents, etc. The tax revenues now become negative and the MCPF becomes more negative. On the other hand, the gain in accidents and environment is larger. On the old stretch the situation for the remaining users will also improve. Because there are less users there, traffic will be smoother and there can be a gain in time, fuel use and environment. The effect on accidents is not clear cut. The effect on the users of the other stretch is practically not quantifiable, but will most likely contribute to a larger benefit of the rebuilding.

5. Conclusion

We conclude that, because of the smoother and safer traffic, the roundabout is preferred to the signalised intersection. The sensitivity analysis showed that this result is fairly robust. However we did not take into account a number of things. We did not take into account the time losses, which occur during the rebuilding. Secondly, we kept the number of accidents constant over time and thirdly, we did not consider pedestrians and bicyclists. Factors one and two make that we overestimate the benefits of the roundabout. The third factor most probably leads to an underestimation.

This study also shows that there is need for good data or at least a study on the comparability and transferability of data between countries.

Finally we would like to note that this framework can also be used to study the transformation of an 'uncontrolled 'junction into a roundabout and for small and large roundabouts. However the conclusion will not necessarily be the same. For the effects of the rebuilding on accident, time and environment and the investment cost will differ. Delhaye (2001) found that the rebuilding of an 'uncontrolled' junction into a roundabout, given the assumptions, led to a cost for society.

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