Automatic safety and speed enforcement systems

An economic study

Bachelor’s thesis within Economics
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Automatisk säkerhets och hastighets övervakningssystem

En ekonomistudie

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Abstract

There is a debate in Sweden if the Automatic Safety and speed enforcement systems (SSS) in Sweden are profitable or not. Cost benefit analysis (CBA) is an excellent tool for determining the economy of traffic safety measures. The parameters of the CBA in this work include: tire wear, fuel consumption, environmental pollution, saved lives and injuries, reduced material damage, time for disputing tickets, time in traffic lines due to accidents, longer time due to lower speed and collected fines and maintained cost for the SSS.

The sensitivity analysis shows that the SSS system appears to be profitable and the greatest uncertainty arises from the calculation of saved lives. Each SSS will on average generate a profit of approximately 250,000 SEK annually.
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### Acronyms

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<th>Description</th>
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<tbody>
<tr>
<td>SSS</td>
<td>Speed Safety System</td>
</tr>
<tr>
<td>ATK</td>
<td>Automatisk TrafikKamera (SSS in Sweden by Vägverket)</td>
</tr>
<tr>
<td>RPS</td>
<td>Swedish National Police</td>
</tr>
<tr>
<td>VSL</td>
<td>Value of Statistical Life (aka VoSL)</td>
</tr>
<tr>
<td>CBA</td>
<td>Cost Benefit analysis (aka BCA)</td>
</tr>
<tr>
<td>CV</td>
<td>Contingent Value (aka CVM)</td>
</tr>
<tr>
<td>WTP</td>
<td>Willingness To Pay</td>
</tr>
<tr>
<td>NRA</td>
<td>Vägverket - Swedish national Road Administration (aka SNRA)</td>
</tr>
<tr>
<td>SA</td>
<td>Sensitivity Analysis</td>
</tr>
<tr>
<td>$k$</td>
<td>Compensation factor due to late arrivals as a result of an accident</td>
</tr>
</tbody>
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1 Introduction

In 1997 the Swedish parliament decided on “vision zero”, this means no one should be killed or seriously injured in or due to road traffic. One goal along the way is to decrease the number of dead by 50% or 270 people by 2007 (Prop 2003/2004:160). According to the Swedish Road Administration there are three major problem areas in achieving the vision zero goals:

1. Two wheeled vehicles, e.g. motorcycles.
2. Alcohol
3. Speeding

If all vehicles drove at the legal speed limits, there would be 140 – 150 less killed each year (Vägverket, 2008a). There are two ways of attacking this problem: either the motorist has to be kept below the speed limit or if something happens the consequences have to be limited. An example of the latter in Sweden is a fence between opposing lanes and an example of the former is a Speed safety system (SSS).

The increasing number of SSSs along the roads as well as the increasing number of speeding tickets received by the public, has caused the SSS to be widely discussed, for and against (Vägverket, 2009b; Keenan, 2004; Söderlind, 2008; Dagens Nyheter 2009; Bergdahl, 2007; Wall, 2009; Edman, 2009).

One of the discussions is regarding if the systems are profitable or not. The Swedish Road Administration that purchases and maintains the SSSs in Sweden has given out an extended variety of reports on SSSs on the saving of life. There are also calculations from other sources that claim that the installation and probable decreased speed actually cost more than they save (Wall, 2009, Edman, 2009, Dagens Nyheter, 2009). Others argue that the SSSs do not save lives but rather that then result in the number of deaths increasing (Söderlind, 2008). This leaves an open door on the subject of the economy of SSSs in Sweden.

The usual way to evaluate the impact of traffic measures is to use cost benefit analysis (CBA) (Eliasson, 2002, Hiselius, 2005, SIKA, 2008 a-b, Taylor, et al. 2000, Vodden, et al. 2007). However, due to difference in basic assumptions, the resulting calculations may differ dramatically (Wall, 2009; Edman, 2009; Väg och trafikforskningsinstitutet, 2004; Vägverket, 2009b). As Flyvbjerg, et al. (2002, 2005) showed there is a significant sensitivity to input parameters and basic assumptions.

Even though there has been a number of surveys and investigations on SSSs, there have been none that cover the Swedish situation which is aiming towards safety rather than income through fines. There are also some question marks in the international surveys regarding the behaviour in terms of acceleration and deceleration, etc of motorists approaching an SSS. This has also been an issue for criticism on how profitable the systems actually are.

1.1 Outline and purpose

This thesis will investigate how profitable installations of SSSs in Sweden really are from a society point of view, not only their profitability for the police or Road Administration.

The paper is divided into six sections including this one. The second section will cover the history of the SSS in Sweden and give the necessary organisational background. The section following that will give the theoretical background to all calculations and methods used. As the speed reduction is a key element, the actual decrease in speed and the manner it is
accomplished in is covered in the empirical measurement part. The cost and benefit analysis and sensitivity analysis are covered in the empirical calculations section. The last section provides conclusions and suggests future work.
2 History of the Speed safety systems in Sweden

In 1996 the Swedish National Police Board started a trial version of automatic traffic safety controls. It was a version that included much manual labour since there were only a limited number of cameras for all the systems. So when measuring on a test site the police had to come there and set up the system, measure for a while and then come back and empty the system. Still today there is a misunderstanding that the new system does not contain any camera most of the time. In 2006 the Swedish Road Administration purchased and started to install approximately 700 speed safety systems all over Sweden. Later these were followed by 300 more.

The organisation behind the SSSs in Sweden is diverted between several different authorities. The systems are all remotely controlled by a unit within the Swedish National Police Board and positioned in Kiruna (ATK-enheten). This is also where all the speeding tickets are investigated and the driver is identified. If the driver argues against a ticket, this will be a case for the Swedish prosecuting authorities who can present and work the cases that have to go to the Swedish court.

The Swedish National Road Administration (NRA) purchases and maintains the systems on the roads. The purchases are done by NRA centrally but the maintenances are done by the different regions. The money from the tickets goes directly to the ministry of finance.
3 Theoretical framework

The economic analysis is made through cost benefit analysis (CBA). Over the decades since first implemented, this method has not been uncontroversial as a mean for prioritising traffic safety measures. The controversy spans from pricing a life (Haukeland, 1994 and Hauer, 1994) to the great task to cover all and not too many costs (Flyvbjerg, 2003, 2005 and Elvik, 2001). One of the first to point out the overwhelming task of CBA for traffic safety was Joksch (1975). In recent years, however, there have been a number of defenders of the theory (Lindberg, 2006, Chen et al., 2006; Brent, 2006; Boardman and Elvik, 2001). These defenders have also proven that CBA, although not an easy task, gives reliable results and have shown the necessity of sensitivity analysis (Chen, 2006).

3.1 Cost benefit analysis in the transport sector

Since the decision making in the transport sector needs to have an economic, the Swedish Road Administration has used, along with many other authorities, CBA since the 1960’s (SIKA, 2008a). Covered here will be the theoretical background needed for a cost benefit analysis for the SSSs in Sweden.

Using CBA is not an easy task as there are many factors to be considered for a wide range of actors. According to Hiselius (2005), there are five effects to have in mind when it comes to CBA and traffic:

1. Economic effects of the traffic, e.g. construction costs, maintenance cost, revenue and operational cost of the transporters sector.
2. Effects imposed on those taking part in the activity, e.g. travel time, travel comfort, safety and accessibility.
3. Effects imposed on those not taking part in the activity, such as people waiting for someone delayed or injured due to an accident. There are many other aspects of this point which are not covered by this thesis since they are considered negligible. Standberg (2009) points that other people than those in the vehicles are not covered.
4. Environment and land use effects.
5. General effects, e.g. equality between the sexes and economic activity in the area. In the line of Hiselius (2005) this point can be considered negligible in the transport sector.

As stated previously the costs and incomes from the SSS project in Sweden are widely spread between different budgets and institutions. Hence the focus of the CBA will be on the effect of the SSSs on the Swedish society, which consists of more than 9 million Swedes. This focus is in contrast to Chen et al. (2006), who focused on how SSS affects the “Canadian NRA”, and is more in the line of Gains et al. (2004) and Elvik (1997), who focused on a whole society. Included in this analysis is for instance fuel consumption and tire wear.

3.1.1 Value of statistical life

Value of statistical life (VSL) is one of the key elements when it comes to CBA and traffic implementation. That there is money to be saved by saving life is maybe a cynical but true statement (Elvik, 2001). Note that VSL does not mean the value of life for an individual but the difference in the common welfare if the number of deaths in traffic is decreased from for instance 7 per 100,000 vehicles to 4 per 100,000 vehicles given a certain amount of traffic per year.
There are several ways to calculate the VSL. They can be divided into three different categories:

1. Through the victims medical and rehabilitation cost.
2. Through the loss of production capacity due to the victims inability to work, that relate to how much money society is going to earn if the statistical person is living on and how much the death or accident costs (Evans L., 2006)
3. Through the physical and medical pain of the victim and their families.

A monetary equivalent can be found for the first two categories (Evans, 2006; Alfaro et al., 1994; Persson et al., 1995) using a methodology referred to as the human capital approach which is restricted to material losses (gross production loss). The third category, often referred to as human costs, is harder to calculate.

One way to calculate the human costs is to use the willingness to pay (WTP) approach. This includes both the two material components and an immaterial component (human losses) and therefore also includes an estimate of gross production loss. To avoid double counting, gross production loss should be deducted from the VSL, which results in ‘human losses’, or net production loss (Wijnen 2009).

The WTP is found through surveys in which people are asked how much money an individual is ready to pay to increase the statistical life span (Schwab, 1995; Elvik, 1995). It is referred to contingent value studies or method (CV or CVM). The different aspects of designing the questionnaire are a science of their own and are beyond the scope of this thesis (Schwab, 1995; Elvik, 1995, 1997, 2001, 2004, 2006; Flyvbjerg, 2002, 2005; de Blaey, 2003). This type of survey can also be used to find a WTP to avoid injuries. In this thesis, in order to get a fair comparison the same method as the Swedish Road Administration (NRA) is used. The NRA has chosen to use CV or WTP studies on how much people are ready to pay in order to avoid a statistical death (Schwab, 1995; Elvik, 1995, 1997, 2001, 2004, 2006; Hultkrantz et al., 2006; Lindberg, 2006).

As an example of VSL calculation, consider a survey that finds that on average people are ready to pay 600 SEK to decrease traffic mortalities from 7 deaths per 100,000 passing vehicles to 4 per 100,000 given a certain amount of traffic per year. This means that the considered number of saved lives per passing vehicle, \(dz\), is:

\[
VSL = \frac{WTP}{dz} = \frac{600}{(7 - 4)/100,000} = 2,000,000
\]

This gives the value of an avoided fatality. But accidents also cause severely and non-severely injured victims. The definition of the severely injured is if the injured has to stay in the hospital. The definition of non-severely injured is the patient who seeks medical attention but not as severely injured. Note that this does not cover those who are injured but do not seek medical attention but still might cause missed production or other cost for the individual or society.

One problem, found by previous researchers is that there is a difference in WTP depending on education and income (Hultkrantz, et al., 2006). There is also a bigger probability of being part of an accident with lower education/income (SIKA, 2008 and Kopits et al., 2005). This is an area that might need more investigation but it is beyond the scope of this thesis and hence not taken into account. Also not covered is the difference between the genders and age groups, even though there is a difference in education, income and risk of being in a traffic accident (Evans, 2006).
3.1.2 The Unexpected delays

A traffic accident might give a rise to traffic jams and pile ups. They do not only increase the uncertainty in how long time a trip will take with delays (indirect effects) but also creates an economically measurable discomfort due to erratic tempo and tension (direct effect) (Eliasson, 2002 and Luo, et al., 2007). According to Ulrika Hedman at the Swedish Civil Contingencies Agency it takes one hour to clear a road from a traffic accident on average from the moment when the alarm comes to the SOS alarm centres. According to Chen et al. the average time added due to traffic accident in British Colombia Canada is approximately two hours. For the current paper the time estimated is one hour.

There is also an issue of unexpected delays, for instance, as a result of a traffic accident. As in the case of VSL, there is also a problem here how to value a delay, including the extent to which a third party might suffer. The question is how much one is ready to pay to avoid a delay. This is also something that varies with income and social standing (higher salary might cost more money), with whether someone else is involved (a delay is worse if you are late for a meeting), with whether there is a private or common perspective, with the total travel time (when travelling far one has a tendency to include a delay), with the purpose of the journey (business or private journey), with whether the means of transportation is private or not, and with whether the delay is expected or not (if one expects some sort of delay an unexpected delay is not so important). However, for instance the fuel price does not have any impact even though the actual cost of the delay is increasing (Wardman, 2001). This is something of the same phenomena that was behind the calculations on VSL (a traffic accident is also considered to be unexpected but the material costs are much greater than the fuel price). Both Wardman (2001) and Bates, et al. (2001) concluded that a monetary price of one unexpectedly delayed hour is 3-7.5 times higher than the anticipated delayed hour.

3.1.3 The power model

One of the major reasons for installing SSSs in Sweden according to the NRA is that there is a strong correlation between a decrease in speed and a decrease in number of casualties (Vägverket, 2009b). This is something also vital to know when determining the economy of a decreased speed and hence part of the economy of an SSS. The power model is an often used methodology when it comes to determining the relation between speed and casualties. The model can be summarised in terms of six equations that relate changes in the number of accidents or in the number of road users killed or injured in accidents due to changes in the mean speed of traffic. The exact equations are presented in the appendix C.

These results will be used later in this paper when the statistical data is insufficient or needs to be verified.

3.2 Sensitivity analysis

When using CBA, there is always an uncertainty in the input data, differences in which can lead to different results. The investigation of this is called the sensitivity analysis (SA). The most probable result with the most reasonable assumptions is called the base case. The question is if by using other assumptions the conclusions will be altered substantially, i.e. how robust the results are is considered. There are three different types of sensitivity analysis (Brent, 2006 and Boardman et al., 2001):

1. Partial analysis – Change one independent input parameter and hold the other constant. This is the best applied to the most uncertain and influential parameters. It shows which parameter or uncertainty has the greatest influence. It might even show if
any parameter needs further investigation. Partial analysis can also be called independent extreme value.

2. Worst and best case analysis – Change all the input parameters to values that will render the worst or the best case and show the robustness for the whole analysis. Analysts are usually most interested in what happens using the most plausible assumptions but still want to know what happens when the most conservative or least favourable assumptions are used.

3. Monte Carlo analysis – Which distribution of net benefit results from treating the numerical values of key assumptions as draws from probability distributions? The mean value along with the variance indicates the robustness.

The analysis of choice depends on the number of parameters of distributions. Sometimes it is easier to pick out the most probable parameters to avoid big and misguided calculations. Distributions of the input parameters are not always possible to find with a reasonable effort either. In this thesis partial analysis is used. One reason is that it gives easier comparison to other research in the field (Flyvbjerg et al., 2002, 2005 and Chen, et al., 2006). The other reason is that the change of the parameters can be considered to be independent and hence it is very unlikely that all the parameters would divert from the base case.
4 Empirical measurements on the effects of an SSS on speed

The decreased speed near an SSS leads to a number of factors in the cost benefit analysis: direct savings like fuel and tire wear, a decreased load on the environment and decreased cost as the number of dead and injured decreases. As these parameters are influenced by the way the speed is decreased, the behaviour of the decrease also needs to be investigated.

The major reason for installing an SSS is the influence on the speed of the passing motorists. The speed change due to an SSS can have a major impact on the number of casualties and can cause additional economic impacts. This section will cover how much the speed is decreased due to an SSS and how the SSS affects the behaviour of the passing motorists, i.e. if the speed is decreased and increased rapidly or in a more slow fashion.

In order to show the impact of an SSS the speed needs to be measured both sometime before and after the installation. Since the impact of an installation is impossible to replicate over a limited time span as well without a real SSS, this thesis has to rely on the data from NRA (Vägverket, 2007a-p).

The changes in speed due to an SSS can be divided into three different categories:

1. Point speed measurements – The behaviour at one specific point at the SSS.
2. In between - The behaviour of a motorist in between two SSSs on one road.
3. Passing - The behaviour of a motorist approaching and leaving an SSS.

4.1 Point speed measurement

Even when an SSS is not active it is measuring the speed at a certain distance in front of the SSS which gives a good statistical background of the decreased speed compared to the speed in that point before the installation. This subsection will give the resulting speed reduction at those points.

As stated before, the speed measurement statistics (Vägverket, 2007a-p) covers 129 SSSs and approximately 4800 vehicles passing each SSS every day. The statistics are chosen from Vägverket (2007a-o) rather than from a ready report from Vägverket (2009b) since the previous ones offer more data, a higher degree of statistical freedom and more unprocessed data. The average speeds before and after the installation of an SSS are given in Table 1 and Fig. 1. Each measurement was made over a week. As can be seen there is a significant decrease in the average speed, 6.2 % or 4.71 km/h.

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>Before (km/h)</th>
<th>After (km/h)</th>
<th>Decrease (%)</th>
<th>Decrease (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totally</td>
<td>75.98</td>
<td>71.27</td>
<td>6.21</td>
<td>4.71</td>
</tr>
<tr>
<td>50 km/h</td>
<td>54.24</td>
<td>49.46</td>
<td>8.81</td>
<td>4.78</td>
</tr>
<tr>
<td>70 km/h</td>
<td>74.77</td>
<td>68.07</td>
<td>9.02</td>
<td>6.70</td>
</tr>
<tr>
<td>90 km/h</td>
<td>85.61</td>
<td>81.48</td>
<td>4.54</td>
<td>4.13</td>
</tr>
<tr>
<td>110 km/h(^1)</td>
<td>97.9</td>
<td>96.3</td>
<td>1.6</td>
<td>1.60</td>
</tr>
</tbody>
</table>

\(^1\) Note that there is only one SSS covering a 110 km/h speed limit.
Fig. 1 The measured speed before and after the installation of 24 SSSs in Sweden during 2006 (Vägverket, 2007a-q). The solid line represents where the speeds are the same before and after.

4.2 In-between

In the previous subsection the speed at the point a certain amount of meters ahead of an SSS installation was investigated. This subsection will cover the speed reduction over a greater distance near a new SSS.

The data in Table 2 from Vägverket (2007p) is from one road and nine different SSSs which offers the insight into the behaviour of motorist in between and at SSSs on one particular road. At the same time Table 3 from Vägverket (2009b) with 49 different SSSs offers a greater statistical basis. According to Table 2 the average speed decreases 10.8 % in close proximity of an SSS, and 5.5 % in between SSSs. Hence the decrease in speed in-between is approximately half of that at the SSS. This shows that there is an effect between the systems also in between. The average distance that can be considered to be covered is 2.45 km.

Table 2 Changes in speed in close proximity to and in between SSSs on Route 50. (Source: Vägverket, 2007p)

<table>
<thead>
<tr>
<th>Sign speed (km/h)</th>
<th>At SSS Before (km/h)</th>
<th>After (km/h)</th>
<th>Difference (%)</th>
<th>In between SSS Before (km/h)</th>
<th>After (km/h)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 km/h</td>
<td>80.2</td>
<td>70.3</td>
<td>12.4</td>
<td>81.5</td>
<td>75.9</td>
<td>6.9</td>
</tr>
<tr>
<td>90 km/h</td>
<td>89.8</td>
<td>81.5</td>
<td>9.2</td>
<td>91.8</td>
<td>88</td>
<td>4.1</td>
</tr>
<tr>
<td>Mean¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.8</td>
<td></td>
<td></td>
<td>5.5</td>
</tr>
</tbody>
</table>

1) Equally weighted on 70 km/h and 90 km/h.

Table 3 Changes in speed in between SSSs on 49 different SSS. (Source: Vägverket, 2009b)

<table>
<thead>
<tr>
<th>Sign speed (km/h)</th>
<th>Before (km/h)</th>
<th>After (km/h)</th>
<th>Difference (%)</th>
<th>Accuracy (km/h)</th>
<th>Difference (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>73.5</td>
<td>69.8</td>
<td>5.03%</td>
<td>± 1.7</td>
<td>3.7</td>
</tr>
<tr>
<td>90</td>
<td>89</td>
<td>85.8</td>
<td>3.60%</td>
<td>± 0.5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

1) Information was also available at 50 km/h but excluded as it was based on only one measurement point.
As can be seen there is a significant difference in decrease in speed reported in Table 2 from that of Table 1. It may be attributed to a wider variety of investigated roads in Table 1 (Vägverket, 2007p). If the numbers in Table 1 are assumed to be more correct on the basis that they cover more different roads, the data in Table 1 can be extracted to cover also in between. Suppose there is a constant ratio between the decrease in speed in between SSSs and at an SSS of approximately 0.5. Given the average 6.1 % speed reduction at an SSS reported in Table 1, this would mean that the average decrease in speed in between SSS is 3.1 %. This is slightly lower than what is reported in Table 3, where the decrease is 3.60 and 5.03 % for SSSs at 90 km/h and 70 km/h respectively. Also shown in Vägverket (2009b, 2007p) is that the SSS has an impact on traffic from the opposite direction, as the average speed decreases almost the same as in between the SSS. The reason for this behaviour is probably due to that the motorists are being reminded of the SSS and that there might be some systems placed also in his or her direction.

4.3 Behaviour approaching an SSS

The investigation of speed in between does not cover the behaviour of the decrease/increase, i.e. this does not say anything if the passing vehicles are slowing rapidly before the SSS or if the vehicles are slowing down slowly. This section will cover the acceleration and retardation before and after an SSS.

According to Gordon et al. (1996) and Fitzgerald (1937), there is a significant difference in fuel consumption and tire wear depending on the manner in which the change in speed is taking place. This means that in order to measure the full extent of the economic impact, the behaviour of the motorist in close proximity of an SSS needs to be investigated in order to fully calculate the economic impact of an SSS.

To consider this issue, a measurement is made at Tolkabro along route 40 in Sweden between Ulricehamn and Borås by the author. The measurement is carried out with Sensys Traffic RS240 tracking radar. The tracking radar can follow a vehicle over 400 m with more than 20 samples per second (both departing and arriving) and thereby show the behaviour of decrease/increase in speed before and after an SSS. RS240 is also the radar which NRA uses in all SSSs in Sweden.

The test site in Tolkabro consists of two systems from NRA, one in each direction. There are 5 sites on the road between Borås and Ulricehamn (approx 9 km). The speed limit in the measurement area is 60 km/h. Just before and after the speed limit is 80 km/h. The traffic is measured over 500 vehicles in each direction. In order to see the speed for all vehicles in a more reasonable way, the average speed is calculated. The results can be seen in Fig. 2. The average speed of vehicles near the SSS (up to 40 m after) is 55 km/h and further away it increases linearly up to 80 km/h 350 m away (the final part is a separate measurement out of the figure). The number of vehicles that were speeding 100 m in front of the SSS (speed higher than 60 km/h) was almost 25%. For arriving vehicles the speed can almost be considered constant from 250 m (close to the same as the visibility range of the SSS) and decreases rapidly up to the SSS. The number of vehicles speeding when approaching the SSS is less than 20 %. The approximation of a vehicle passing an SSS can be seen in Fig. 2 a faster decrease in the beginning and a slower increase in the end after passing the SSS.

The behaviour of drivers on changing speed while approaching an SSS is also given in Fig. 2. These results need to be generalized to fit the data from the data from the two previous sections (Table 1 - Table 3). From the previous section we know that there are 2.45 km covered by an SSS and the speed reduction (with and without an SSS) is between 2.35 and 4.71 km/h. How big this decrease is depends on how close the vehicle is to the SSS according
to Fig. 2. To generalize these results (Table 1 - Table 3 and Fig. 2) - the speed is decreasing from 75.98 km/h to 71.27 km/h but it takes place over 600 m with a rapid deceleration in the beginning in two steps and a slower acceleration over 300 m after the passing. It means that it will take 4.5 s more to pass an SSS.

Fig. 2 Theoretical speed vs. distance for traffic passing two SSSs where the speed limit is 60 km/h and 80 km/h before and after (Tolkabro, RV40).

The conclusion is that over all SSSs the average speed decrease is from 75.98 km/h to 71.27 km/h, 4.71 km/h or 6 % (Table 1). In the Tolkabro example the effect is in even more extreme with a reduction of 76 to 55 km/h over 600 m (Fig. 2). The average speed in between changes is approximately 3 % (Table 2). The passing behaviour of the motorist at one particular site (two SSSs) can be seen in Fig. 2. This behaviour is considered to be qualitatively valid for all SSSs.
5 Empirical calculations on costs and benefits from an SSS

This section covers the actual monetary calculations for the cost and benefit analysis. All the results will be summed up in a base case scenario with the sensitivity analysis presented subsequently in order to consider the robustness of the results.

5.1 The direct savings of decreased speed

When using CBA there is a cost directly affecting those taking part in the activity (Hiselius, (2005) second point) and it will be covered in this section. As already stated, the direct effect of decreasing the speed is a decrease in fuel consumption and tire wear while other effects like decreased wear on the vehicles are neglected. The aim of this section is to correlate the reduction of speed to how much money is saved. These savings are found by investigating the decrease in fuel consumption and tire wear at between certain speeds.

The tire wear (per 10 km) is given by Teknikens Värld (April 2000) where the percentage change in tire wear due to a small increase (or decrease) in speed is given in a graph by Fitzgerald (1937). The graph is presented in Appendix E. The tire wear is assumed to be independent of the vehicle and hence an average tire is used. There is a significant change in tire wear but this can be expected as it also increases with the square of the speed.

The tire wear reduction due to an SSS is calculated by assuming a decrease in speed by 4.71 km/h (from 75.98 to 71.27 km/h) as estimated in subsection 4.3. If the acceleration and retardation are neglected, the tire wear decreases by 1.1 % as can be seen from Appendix E and Fitzgerald (1937). A decrease by 1.1% means that the saving is 0.01 SEK per vehicle (Teknikens Värld, April 2000). A more careful calculation is shown in appendix F. There are 2,128,988 vehicles passing an SSS on average (Vägverket, 2008b), leading to a total decrease of 21,290 SEK in tire wear per year per SSS.

The fuel consumption (per 10 km) is given by Teknikens Värld (April 2000). There is a significant change in fuel consumption but this can be expected with an increase with the square of the speed. The fuel consumption is derived for a Volvo V70 from Teknikens Värld (Teknikens Värld, April 2000), since this is the most popular car in Sweden. The behaviour of the fuel consumption for various speeds is shown in Fig. 3.

Whereas the tire wear was relatively simple to calculate, the amount of saved fuel is slightly more complex. Based on the reduction in speed by 4.71 km/h (from 75.98 to 71.27 km/h) and the formula derived from Nordling et al (2004) to calculate the effect of speed changes on fuel consumption, the average SSS is found to save approximately 3.0942 ml per passing vehicle and SSS. The calculations are shown in Appendix D. The fuel price is set to 12.52 SEK/L (Teknikens vårld, 2009). So with 2,128,988 vehicles passing each SSS on average a year, the total saving for an SSS in decreased fuel consumption is 82,476 SEK per system and year.

On average the lost time is 4.5 s, saved fuel 3.1 ml and spared tires 1.1 %. Per SSS on average it means 21,290 SEK in tire wear and 82,476 SEK in fuel in annual savings.
5.2 Environment

The protection of the environment is, of course, a major argument for an SSS in the times of global warming and an increasing interest in environmental issues. This section will cover the costs for the pollution of the passing vehicles and the change in it due to an SSS. The aim is to calculate the cost from exhaust from nitrogen (NOx), CarbonHydrats (HC) and carbondioxid (CO₂) as the speed decreases from 75.98 to 71.27.

Data on the costs of these emissions have previously been made available only at 88 and 91.5 km/h for 2004 (Statens Väg och Trafikforskningsinstitut, 2004) and these can be seen in Table 4. The information from these points is used to impute the costs for 75.98 km/h and 71.27 km/h based on the assumption that the relationship between speed and costs is linear. The prices are also compensated in order to reflect 2006 year prices.

With this the total sum is 0.0317 SEK per SSS and vehicle which means 67,480 SEK in less environmental costs annually per SSS.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>NOx (SEK/km)</th>
<th>HC (SEK/km)</th>
<th>CO₂ (SEK/km)</th>
<th>Totally (SEK/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>88¹</td>
<td>0.0341</td>
<td>0.0084</td>
<td>0.2505</td>
<td></td>
</tr>
<tr>
<td>91.5¹</td>
<td>0.0356</td>
<td>0.0092</td>
<td>0.2554</td>
<td></td>
</tr>
<tr>
<td>75.98²</td>
<td>0.0326³</td>
<td>0.0174³</td>
<td>0.1064³</td>
<td></td>
</tr>
<tr>
<td>71.27²</td>
<td>0.0305³</td>
<td>0.0163³</td>
<td>0.0998³</td>
<td></td>
</tr>
<tr>
<td>Additional cost/km (SEK)⁴</td>
<td>0.0020</td>
<td>0.0011</td>
<td>0.0066</td>
<td></td>
</tr>
<tr>
<td>Cost/SSS, vehicle (SEK)⁵</td>
<td>0.00546</td>
<td>0.00291</td>
<td>0.01783</td>
<td></td>
</tr>
<tr>
<td>2006 level⁶</td>
<td>0.0066</td>
<td>0.0035</td>
<td>0.0216</td>
<td>0.0317⁷</td>
</tr>
<tr>
<td>Cost/SSS (SEK)⁸</td>
<td></td>
<td></td>
<td></td>
<td>67,480</td>
</tr>
</tbody>
</table>

1. The costs from Statens väg och trafikforskningsinstitut (2004)
2. From behaviour approaching an SSS chapter.
3. Linear combination of the values given for 88 and 91.5 km/h as given in Appendix A

Fig. 3 Fuel consumption Volvo V70 2.4 T (Source: Teknikens Värld, April 2000).
4. Cost for 75.98km/h minus cost for 71.27 km/h.
5. Cost/km * 2.7 km/SSS and vehicle.
6. Values from Cost/SSS vehicle is multiplied by the ratio of the 2006 price level to the 2004 price level (ASEK 4 (SIKA 2008a)).
7. The total sum per SSS and vehicle of NOx, HC and CO2.
8. The cost per SSS and vehicle times approx 2.1 million vehicles annually.

5.3 The lifesaver

When the SSS was introduced, it was as a lifesaver. This section will investigate the number of lives, severely injured, non-severely injured and crashes that are avoided due to an installation of an SSS. It is accomplished by summing up the data from the NRA (National Road Administration) comparing to the theoretical models (power model) and similar surveys in other countries. The data is then used for calculating how much money is saved by avoiding these casualties.

In 2009 the NRA (Vägverket, 2009b) released a report on the casualties on the roads that have been fitted with SSSs or replacing old type of SSSs during 2006. There were 682 of the SSSs affecting 1,730 km passed by 5,833 vehicles daily. The results can be seen in Table 5. The deaths without SSSs are calculated through the number of deaths 2003-2005 which are then recalculated to the 2006 level using the total number of deaths on the road in Sweden and the number of km driven each year (Vägverket, 2009b).

Table 5 Extrapolated number of deaths and casualties (dead and severely injured) for roadway near 682 new or replaced SSS in Sweden. Source: Vägverket, 2009b

<table>
<thead>
<tr>
<th>Deaths without SSS1</th>
<th>Deaths with SSS2</th>
<th>Difference in Deaths %</th>
<th>Difference death Absolute no</th>
<th>Severely injured without SSS3</th>
<th>Severely injured with SSS4</th>
<th>Difference Severely injured Absolute No</th>
<th>Difference Severely injured %</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.4</td>
<td>28</td>
<td>-32.4%</td>
<td>-13.4</td>
<td>189.9</td>
<td>155</td>
<td>-34.9</td>
<td>-18.3%</td>
</tr>
</tbody>
</table>

1) Number of dead prior to 2006 normalized to 2006 years level.
2) The actual number of dead in the roads covered by SSS in 2006.
3) Number of severely injured prior to 2006 normalized to 2006 years level.
4) The actual number of severely injured in the roads covered by SSS in 2006.

As can be seen there is a significant change in the number of deaths and severely injured. Note that there is a limited statistical significance in the table, especially considering the number of deaths. More investigations are promised by the NRA in the future (Vägverket, 2009b).

There have been previous and other investigations on the decrease in number of causalities and some of them are given in Table 6. Also given is the estimated decrease in dead, injured and material damage predicted by the power model at 7 % decrease in speed (Statens väg och trafikforskningsinstitut, 2004) and at 6 % as calculated in subsection 4.3.

The numbers given from VTI (Statens väg och Trafikforskningsinstitut, 2004) was from a pre-study on a limited amount (10) of SSSs placed in Sweden on strategic roads 2003-2006. These were the data used to decide on the implementation of SSS in Sweden and used here as a comparison.

In the last column of Table 6 the results of Pilkington et al. are also presented for comparison. They investigated a number of international surveys of the lives saved by using SSSs. The number of saved lives is between 17-71%. There is no data for severely injured but the total
number of injured is between 12 % and 65% and the number of crashes avoided is -5 % to 69%. This shows of a great span due to both uncertainty as well as sensitivity to where they are placed and how they are used. However, what it shows is that the data from the left in Table 6 is within the international interval. therefore considered to be plausible.

Table 6 The change in number of casualties due to SSSs.

<table>
<thead>
<tr>
<th></th>
<th>Initial SSS test by VTI 2004 (%)</th>
<th>Power model 7 % speed reduction (%)</th>
<th>Change from SSSs Table 5. (%)</th>
<th>Power model 6 % speed reduction (%)</th>
<th>Pilkington et al. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead</td>
<td>-60</td>
<td>- 28</td>
<td>- 32.4^4</td>
<td>- 25</td>
<td>- 17 to -71</td>
</tr>
<tr>
<td>Severely injured</td>
<td>-11</td>
<td>- 20</td>
<td>- 18.3^4</td>
<td>- 17</td>
<td>x</td>
</tr>
<tr>
<td>Non-severely injured</td>
<td>+6.9</td>
<td>- 18</td>
<td>- 16</td>
<td>- 12 to -65</td>
<td></td>
</tr>
<tr>
<td>Material damage</td>
<td>x</td>
<td>- 14</td>
<td>- 12</td>
<td>- 5 to -69</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>-7</td>
<td>- 7</td>
<td>- 6.2^5</td>
<td>- 6.2</td>
<td></td>
</tr>
</tbody>
</table>

1) The figures are from Statens väg och trafikforskningsinstitut (2004). They originate from an initial test of 10 SSS placed in Sweden during 2003 onwards.
2) The power model applied to the 7 % decrease in speed reported in Statens väg och trafikforskningsinstitut (2004).
3) Pilkington et al. (2005) put together a lot of results of different SSS from all over the world, the figures originate from these references.
4) Data from Table 5.
5) The speed is calculated in the behaviour approaching SSS chapter.
6) The power model applied to speed decrease found in chapter 3 (~6 %).

As can be seen there is a significant decrease in fatalities and injuries to be anticipated from all the columns but the extent varies dramatically. The decrease in dead and severely injured from SSSs follows the power model with a slightly higher number of dead. The values in the references in Table 6 are slightly on the higher side compared to the calculated and given values in the right hand columns but they are within the interval.

A small discussion surrounding this data might be in order. The decrease in speed in close proximity to the SSS is, as could be seen in chapter 3, higher than that in between. At the same time the distance in between SSSs is much greater than that covered by the SSS. However, one must remember that the SSS is positioned at the most dangerous parts of the road (Vägverket, 2009a). If the decrease in speed from chapter 3 is used over the whole distance influencing a decrease in speed, the number of reduced casualties will be underestimated.

In order to calculate the number of non-severely injured and hence the material damage the power model can be used along with the total number of non-severely injured people in Sweden.

5.3.1 The savings of a lifesaver

This section treats the net monetary benefit of SSS as a result of avoided deaths, severely injured, non-severely injured and property damage with the help of value of statistical life (VSL). VSL is determined by an individual’s marginal willingness to pay for a decrease in death due to an accident, as was described in the Value of statistical life section.
As the actual costs already have been determined, the work that remains is to decide on the number of avoided deaths, severely injured, non-severely injured and property damage by the introduction of SSSs. From Table 5 the annual number of death and severely injured avoided due to the introduction of SSS can be seen. However, not stated in the statistics from Vägverket is the number of non-severely injured and the number of collisions resulting in material damages that are avoided. One way to extract the number of non-severely injured is by assuming the same ratio between the numbers of non-severely injured and the number of deaths or severely injured respectively as on all national roads. These calculations are done in Appendix B. The resulting figures (1,015 and 135 respectively) differ dramatically so the number calculated from the number of severely injured will be used as this number is a lower estimate and should be considered more accurate following the discussion in the previous section. Also the number of material damages (collisions where there was enough material damages that has to be covered by an insurance company) avoided are not given in the statistics for SSSs and hence has to be extracted. It is done through Folksam (2009) as there are 29,000 non-severely injured on 105,000 material damages for cars. Note that these values from the insurance company Folksam (2009) differ dramatically from those published by SIKA (2009) based on damage reported to the police where there was 1.5 dead, severely injured or non-severely injured per damaged vehicle. Using Folksams values means that 490 material damages would be avoided.

According to Evans (2006) the total cost of all deaths should be 1.8 times lower than all the material costs (including all injuries) due to accidents, but from the assumptions above, the costs for injuries are 1.1 times. This indicates that those assumptions are not totally wrong.

The resulting values of deaths, severely injuries, injuries and material costs are given in Table 7. Also given are the material costs according to ASEK 4 (SIKA, 2008a). It consists of costs for healthcare, net production loss, property damage and administration. Not included is difference in risk of an accident for different groups of the society (SIKA, 2008b); also something which is not included is the influence of a traffic accident on surrounding traffic, for instance, lines and consequent delays but more on this further down. The amount from the number of deaths is the biggest contributor, almost as big as the other ones put together. This number is also the most uncertain number. In the overall traffic the costs and number of accident are summed in Table 7.

Also given in Table 7 is the highest possible value based on the initial estimations (20 deaths and 70 severely injured avoided) from before the ATK project started (Vägverket, 2008c). The number of non-severely injured and material costs is calculated in the same way as above but the higher estimate is chosen.
Table 7: The costs for the society of a traffic accident in 2006 value according to SIKA (2008b).

<table>
<thead>
<tr>
<th>Per casualty or collision</th>
<th>Risk value cost $^1$ (kSEK)</th>
<th>Material costs $^1$ (kSEK)</th>
<th>Number avoided by SSSs based on Table 6</th>
<th>Total Cost all SSS $^4$ (kSEK) using Table 5</th>
<th>Number avoided by SSSs based on VTI (2004)</th>
<th>Total Cost all SSS $^{10}$ (kSEK) using VTI (2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4): $^*$((1)+(2))×(3)</td>
<td>(5): $^*$((1)+(2))×(5)</td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>21 000</td>
<td>1 321</td>
<td>13.4$^4$</td>
<td>299 101</td>
<td>20$^7$</td>
<td>446420</td>
</tr>
<tr>
<td>Severe injured</td>
<td>3 485</td>
<td>600</td>
<td>34.9$^3$</td>
<td>142 567</td>
<td>70$^9$</td>
<td>285950</td>
</tr>
<tr>
<td>Injured</td>
<td>133</td>
<td>166</td>
<td>135$^5$</td>
<td>40480</td>
<td>1497$^8$</td>
<td>447693</td>
</tr>
<tr>
<td>Material damage</td>
<td>14</td>
<td>14</td>
<td>490$^6$</td>
<td>6863</td>
<td>5421$^9$</td>
<td>75898</td>
</tr>
<tr>
<td>Total cost SSS annually</td>
<td></td>
<td></td>
<td></td>
<td>489010</td>
<td>1255961</td>
<td></td>
</tr>
<tr>
<td>(SEK)</td>
<td></td>
<td></td>
<td></td>
<td>717 024</td>
<td>1841 585</td>
<td></td>
</tr>
</tbody>
</table>

$^1$: The cost per actual accident and dead, injured or accident from ASEK 4 (SIKA 2008a)
$^2$: The theoretical distributions of casualties over a year (SIKA 2008b)
$^3$: The number of deaths and severely injured avoided from Table 6.
$^4$: (Risk value cost (cost for society) + Material costs (actual cost))*No calculated, the most probable value.
$^5$: Values calculated based on the column to the left as well as the values on top.
$^6$: Values calculated on the value immediately above and Folksam (2008).
$^7$: The number of deaths and severely injured avoided from the initial estimations Vägverket (2008c).
$^8$: Values calculated with the higher estimate based on the column 4 as well as the values on top.
$^9$: Values calculated based on the value immediately above and Folksam (2008).
$^{10}$: (Risk value cost (cost for society) + Material costs (actual cost))*No calculated, the highest value.

These values can now be used to calculate the amount of money saved by using SSSs in Sweden per year. By assuming 13.4 lives, 34.9 severely injured, 135 non-severely injured and 490 number of material damages avoided annually, it means that every year the lifesavers save 489,010,358 SEK/year or 717,024 SEK/SSS and year.

The average weighted speed was decreased from 75.98 to 71.27 km/h as described in the speed section. The uncertainty in this decrease can be assumed o be +/- 3 km/h. By using the power model the changes in saved lives due to this can be calculated to be 5.2 and 20.5 respectively. In the same way the difference in severely injured (13.2 and 54.8), non-severely injured (216 and 908) and accidents (773 and 3,336) can be estimated. The total savings in SEK per SSS and year will be 276,424 and 1,107,692 respectively.

5.4 *Time loss or time gain.*

By decreasing the speed one can imagine that motorist would have to spend more time on the roads but at the same time, some time is won as there will be fewer lines and direct time loss due to accidents. The goal of this section is to investigate if there is a time loss or gain.
In the previous section it was stated that 490 accidents were avoided each year due to installations of SSSs. It takes one hour to clean an accident on the national Swedish roads in residential areas according to Ulrika Hedman at the Swedish Civil Contingencies Agency. The corresponding number for Canada is 2 hours per accident (Chen et al., 2006). It means that each year will be spared of 119,132 hours of standstill traffic. On average, 5,833 vehicles pass each SSS every 24 hrs and with one hour delay per vehicle (243 hours per collision) and 490 collisions per year there will be 119,132 (243×490) hrs per year.

Unlike the delay due to decreased speed passing an SSS, the accident cannot be anticipated. The effect of an accident is that the trip will take considerably longer time as well as a risk of not getting to the target on time causing delays also for others. According to the references of Eliasson (2002), the compensating factor for these two consequences is 3-4 times higher. This means that if an accident takes one hour standing in line for one vehicle, the actual cost for the society is between 3-4 hours. However, there is a great uncertainty in this number. The compensation factor, referred to as \(k\) in this work, is the factor multiplied with the actual delay due to an accident to approximate the actual overall hours lost. An aspect in the matter is, as already mentioned, that the SSSs are placed in such places where it is usually very hard to pass in case of an accident as well as where there is an increased risk of accidents. These reasons cause considerable irritation and lack of comfort and it is beyond the scope of the thesis to value both, i.e. no economic estimations will be made. The compensation factor was chosen to be 3.6 as this is the approximate average found in the references of Eliasson (2002) and Chen et al. (2006). However, this factor has a large uncertainty, so for the sensitivity analysis the extreme values 1 and 4 are also chosen. The first means that no compensation is given to any third party and 4 is the highest value found in the references Eliasson (2002) and Chen et al. (2006).

Another effect that has to be considered is the time lost due to disputing tickets. Chen et al. (2006) calculated that each disputed ticket cost approximately 3 hours, which in Canada resulted in the cost of 1 million US dollars. In 2007 in Sweden 2000 cases of 130,000 (1.5 \%) were either disputed or for some other reason sent to prosecutor. In analogy with the Canadian case, the Swedes spent 6,000 hours disputing tickets and no costs for council are included due to the small sum involved. In ASEK 4 the recommendation of delay costs is 275 SEK/hr (Vägverket, 2008a).

As the speed is lowered while passing an SSS, each motorist that passes will lose some time and his total travelling time will increase. The time lost by each motorist passing each SSS is 4.5 s with approx 5800 vehicles passing each SSS every 24 hours means that the total delay is 1,813,308 hours/year (4.5 s ×5,800 vehicles/day × 365 days in a year × 685 SSSs in Sweden / 3,600 s/hour).

The assumption of decreased speed chapter was that the speed decreases by 4.71 km/h due to the installation of an SSS. If instead the average speed changes to 1.71 or 7.71 both the time spent on the road will increase and decrease respectively but the time due to accidents will decrease and increase respectively. The time spent for tickets is assumingly the same. These alternate values are used in the sensitivity analysis.

As already seen in previous chapters there is a big uncertainty in the number of crashes, something which also influences the time spent. The values used here are the extreme values calculated in Appendix B.

The total time loss or time gain due to the SSS is given in Table 8. Included here are also all the other cases which are the of the sensitivity analysis that was discussed in this section.
Table 8 Time loss or time gain due to the SSS. The fourth column gives the base case.

<table>
<thead>
<tr>
<th>Speed change</th>
<th>1.71</th>
<th>4.71</th>
<th>7.71</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compensation factor</td>
<td>3.6</td>
<td>Compensation factor</td>
<td>3.6</td>
</tr>
<tr>
<td>1(^8)</td>
<td>1(^8)</td>
<td>1(^8)</td>
<td>1(^8)</td>
</tr>
<tr>
<td>Crashes</td>
<td>182</td>
<td>Crashes</td>
<td>490</td>
</tr>
<tr>
<td>Time loss due to lower speed (Hours)(^3)</td>
<td>642848</td>
<td>1813308</td>
<td>1813308</td>
</tr>
<tr>
<td>Time gain due to less accidents(^4)</td>
<td>159315</td>
<td>119132</td>
<td>0</td>
</tr>
<tr>
<td>Hours disputing tickets(^5)</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Total time loss per SSS(^6)</td>
<td>718</td>
<td>2493</td>
<td>2668</td>
</tr>
<tr>
<td>Total money loss per SSS(^7)</td>
<td>197392</td>
<td>685555</td>
<td>733592</td>
</tr>
</tbody>
</table>

1) The compensation factor due to delays being unexpected and influencing third party (Eliasson, 2002).
2) The average decrease in speed while passing an SSS.
3) The number of hours lost in total due to the decreased speed above.
4) The time gained due to fewer accidents including the compensation factor.
5) The time the Swedes spend in total due to tickets received by SSSs.
6) Summation of the rows above per SSS.
7) The total cost of the time from above.
8) No compensation for any third party due to accidents.
9) The highest median value according to Eliasson J. (2002).
10) The crashes calculated in Appendix B, Table 5 and Folksam (2008).

5.5 Net monetary benefits

The section will cover the monetary costs and profits of an SSS to the Ministry of Finance, National Road Administration and the Swedish Police, according to Vägverket and Anders Druuge at the Swedish National Police Board. It will also cover some other facts surrounding the SSS in Sweden.

The costs and incomes of an average SSS for government institutions are given in Table 9. Note that there is almost break even after ten years net benefits. After 25 years the actual incomes are substantially bigger than the costs. The total net monetary benefit annually for 10 years is 4,276 SEK and for 25 years 37,689 SEK. This difference is due to that the depreciation of the system is a large part of the whole calculation.
Table 9 The annual actual costs and incomes in 2006 from SSSs in Sweden per SSS according to Anders Drugge at the Swedish National Police Board.

<table>
<thead>
<tr>
<th></th>
<th>SEK (10 years)</th>
<th>SEK (25 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase and start-up costs</td>
<td>-550000</td>
<td>-550000</td>
</tr>
<tr>
<td>Running costs (annually)</td>
<td>-20000</td>
<td>-20000</td>
</tr>
<tr>
<td>Maintain costs (annually)</td>
<td>-35000</td>
<td>-35000</td>
</tr>
<tr>
<td>Interest 2.5%</td>
<td>-7563</td>
<td>-7150</td>
</tr>
<tr>
<td>Depreciation</td>
<td>-55000</td>
<td>-22000</td>
</tr>
<tr>
<td>Fines</td>
<td>+121839</td>
<td>+121839</td>
</tr>
<tr>
<td>Totally</td>
<td>4276</td>
<td>37689</td>
</tr>
</tbody>
</table>

In 2006 with the 652 SSSs fully operational there were 140,000 fines issued with the help of SSSs in Sweden. Due to the increasing number of SSSs, the estimated number of fines in 2008 was 220,000 – 240,000 and the fines increased to 2,000 – 4,000 SEK (approximately doubled), so a bigger income from the fines can be anticipated but the data is currently not available. As can be seen the single SSS installation reaches breakeven for that year after ten years even if only the net monetary benefit is considered. The long time is due to two things: the depreciation is so high per year and the money earned on fines is so low. However, the amount of money gained on fines could be considerably greater if the SSS were turned on more. Currently each SSS takes in on average one speeding ticket per day. The number of violations is approximately 20-40% per system of the passing vehicles and the average of 4,800 vehicles passing each SSS every day. Of the motorists passing and speeding approximately 40% are liable for the ticket. This would mean that there could be from 350 to 750 tickets per system and day if the net monetary benefit of the SSSs were the important issue. However, there is a political consideration to ensure understanding of the system as a lifesaver and not as “money machines” that explains the low level of speeding tickets according to Anders Drugge on ATK-enheten in Kiruna who is responsible for the police part of SSSs in Sweden. A major concern is that with an increased level of tickets from each system there would be an increase in vandalism.

Not included in the net monetary benefit analysis is the cost for a driver losing his driving licence and the costs associated with it like unemployment, driving classes etc.

Another impact of the SSS on the motorist is the fines collected, i.e. the average fines in Sweden per year are 83,000,000 SEK for all 683 systems of 2006. At the same time there are approximately 4,800 passing vehicles per system per day. This means that the average costs in fines are 0.07 SEK/vehicle or that there are 0.12 speeding tickets per day.
5.6 The base case

When doing the sensitivity analysis in this report the base case is the case that is considered to be the most probable. Sensitivity analysis options are evaluated relative to the base case. This case provides the benchmark against which the proposed project can be measured and given in Table 10. As can be seen, the net benefits are positive at 249,411 SEK.

Table 10 The base case for the cost benefit analysis and the chapters in which the numbers are explained.

<table>
<thead>
<tr>
<th>Cost (SEK)</th>
<th>Influencing Factor</th>
<th>From subsection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>82476</td>
<td>Average speed reduction</td>
</tr>
<tr>
<td>Tirewear</td>
<td>21290</td>
<td>Average speed reduction</td>
</tr>
<tr>
<td>Environment</td>
<td>67480</td>
<td>Average speed reduction</td>
</tr>
<tr>
<td>Lives</td>
<td>717024</td>
<td>Average speed reduction The number of lives saved</td>
</tr>
<tr>
<td>Time spent</td>
<td>-560658</td>
<td>Average speed reduction The number of lives saved Compensation factor</td>
</tr>
<tr>
<td>Net monetary benefit</td>
<td>4276</td>
<td>Depreciation time</td>
</tr>
<tr>
<td>Total</td>
<td>249411</td>
<td></td>
</tr>
</tbody>
</table>

5.7 Sensitivity analysis

The sensitivity analysis is vital for a cost benefit analysis in order to determine the stability of the conclusions from CBA. This section will consider the stability of the results by individually investigating the maximum and the minimum values found in the previous sections.

The biggest impact of the sensitivity analysis (Flyvbjerg et al., 2002 and 2005) is the missing and/or neglected parameters but since these parameters are neglected for a reason and the parameters that are missed or forgotten are undetermined, adjusting for these parameters in this analysis is very hard to perform. The sensitivity analysis in this report uses partial value sensitivity analysis as given in Table 11 to Table 14 and following the example of Chen et al. (2006).

The sensitivity analysis is a bit complicated since some data depends on each other at the same time as the assumed result is empirical. An example can be a reduction of the assumed speed, the tire wear, fuel, environment, time spent would decrease in a determinable way but the number of lives is empirically determined. Hence there are many different tables to peruse. As can be seen there is always a profit on each SSS but it varies from little more than 7,000 to more than 3,000,000 SEK per SSS per year. These results are in the in the line of those of Chen et al (2006) which were considered robust. The most left column is the most probable base case. This is also the figures that will be in the other tables as another case is tested.

The parameters varied in the sensitivity analysis are those under discussion in Sweden as well as those used by Chen et al. (2006) in their sensitivity analysis. The parameters omitted from the sensitivity investigation are those considered too small for any major impact (e.g. interest on the systems) or certain enough so the interval is small enough (e.g. fines).
5.7.1 The compensation factor (k)

In the Time loss or time gain subsection (subsection 5.4) it was established that the cost of time lost due to accidents also should include a factor due to the influence it had on a third party or due to that the motorist has to compensate just in case there is a risk of an accident. In that subsection a compensation factor, \(k\), was used to consider this cost, and three values for it were under investigation. The same three values are used here and the effects on the cost-benefit analysis are presented in Table 11.

<table>
<thead>
<tr>
<th></th>
<th>Base case: (k=3.6)</th>
<th>(k=1)</th>
<th>(k=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>82476</td>
<td>82476</td>
<td>82476</td>
</tr>
<tr>
<td>Tirewear</td>
<td>21290</td>
<td>21290</td>
<td>21290</td>
</tr>
<tr>
<td>Environment</td>
<td>67480</td>
<td>67480</td>
<td>67480</td>
</tr>
<tr>
<td>Lives</td>
<td>717024</td>
<td>717024</td>
<td>717024</td>
</tr>
<tr>
<td>Time spent</td>
<td>-560658</td>
<td>-685555</td>
<td>-541444</td>
</tr>
<tr>
<td>Net monetary benefits</td>
<td>4276</td>
<td>4276</td>
<td>4276</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>249411</td>
<td>124515</td>
<td>268626</td>
</tr>
</tbody>
</table>

As can be seen the compensation factor has a significant influence on total net benefits but in no case is there a negative total. The worst negative value for time spent still does not reach half the total number. The maximum difference between the highest and lowest total value is 54% or 140,000 SEK.

5.7.2 The calculated depreciation

The guaranteed life from the manufacturer of the SSS in Sweden is 10 years but the oldest systems have already outlived that and began a second life as mobile SSS units for construction sites (Vägverket, 2008). One reason for this is that there are very few mechanical moving parts (only the camera shutter) and the usage of the SSS is not very intensive (the camera can take more than 100,000 pictures). 25 years can be considered the maximum life for an SSS due to lack of spare parts. Of course, some SSSs get sabotaged or are accidentally run down but this cost is minimal and is covered by spare parts. One reason for low sabotage is that one of the main objectives from the police has been to increase the understanding and sympathy for this work according to Anders Drugge at the National Police Board. The sensitivity analysis presented in Table 12 is based on 10 and 25 years as minimum and maximum lifespans, using the derivation of net monetary benefits given in Table 9.
Table 12 The sensitivity analysis –10 and 25 year depreciation values in SEK/year and SSS.

<table>
<thead>
<tr>
<th></th>
<th>Base case: 10 years</th>
<th>25 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>82476</td>
<td>82476</td>
</tr>
<tr>
<td>Tirewear</td>
<td>21290</td>
<td>21290</td>
</tr>
<tr>
<td>Environment</td>
<td>67480</td>
<td>67480</td>
</tr>
<tr>
<td>Lives</td>
<td>717024</td>
<td>717024</td>
</tr>
<tr>
<td>Time spent</td>
<td>-560658</td>
<td>-560658</td>
</tr>
<tr>
<td><strong>Net monetary benefits</strong></td>
<td>4276</td>
<td>37689</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>249411</td>
<td>282824</td>
</tr>
</tbody>
</table>

As can be seen there is no significant impact of different depreciation. The difference is approximately 12% or 33,000 SEK. Even the net monetary benefits are both positive and independent of depreciation.

5.7.3 The change in average speed

In the empirical measurement section (section 4) the change in average speed was calculated at the SSS, in between SSSs and approaching an SSS. It was also shown how the cost for fuel, tire (direct savings of decreased speed), environment (environment), lives (savings of a life saver) and time spent (Time loss or time gain) was influenced by a change of average speed. Suppose that the speed reduction is covered by +/- 3 km/h compared to the average decrease of 4.71 km/h given in Table 1. This means that the speed reduction is between 1.71 and 7.71 km/h. Otherwise drivers would be expected to follow the behaviour of when passing an SSS as demonstrated in Fig. 2. The results from this sensitivity analysis are given in Table 13.

Table 13 the sensitivity analysis – difference in decreased speed, values in SEK/year and SSS.

<table>
<thead>
<tr>
<th></th>
<th>Base case: -4.71 km/h</th>
<th>-1.71 km/h</th>
<th>-7.71 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>82476</td>
<td>29905</td>
<td>135067</td>
</tr>
<tr>
<td>Tirewear</td>
<td>21290</td>
<td>7720</td>
<td>34865</td>
</tr>
<tr>
<td>Environment</td>
<td>67480</td>
<td>24566</td>
<td>8596</td>
</tr>
<tr>
<td>Lives</td>
<td>717024</td>
<td>276424</td>
<td>1107692</td>
</tr>
<tr>
<td>Time spent</td>
<td>-560658</td>
<td>-197392</td>
<td>-951876</td>
</tr>
<tr>
<td><strong>Net monetary benefit</strong></td>
<td>4276</td>
<td>4276</td>
<td>4276</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>249411</td>
<td>115594</td>
<td>203553</td>
</tr>
</tbody>
</table>

As can be seen there is significant impact from varying the reduction in speed. The difference is approximately 43% or 87,000 SEK. The interval is chosen large enough to ensure that the best and worst expectations are covered (Statens väg och trafikforskningsinstitut, 2004; Vägverket, 2008a; Chen et al., 2006; Gains et al., 2004).

5.7.4 The number of lives saved

As it was seen in subsection 5.3 on the value of an SSS as a lifesaver there is a great uncertainty in the effect the SSSs have on the number of number of dead, severely injured,
non-severely injured and crashes. The lowest number of dead and severely injured can be considered relatively certain but with different assumptions the number of dead and seriously injured that were avoided was estimated to be as high as 20 and 70 respectively. The uncertainty in the numbers of non-severely injured and crashes are even higher as they are based on the number of dead and there is a large amount of non-reported accidents. The results on the cost-benefit analysis from varying these values are presented in Table 14. The values in the fourth column are the utmost extreme values found. The second column assumes that no crashes and severely injured are avoided.

Table 14 The sensitivity analysis – difference due to estimated difference in number of dead, non-severely injured and material cost avoided, values in SEK/year and SSS.

<table>
<thead>
<tr>
<th></th>
<th>Base case: 13.4 dead 34.9 severely injured 490 crashes 135 non-severely injured</th>
<th>13.4 dead 34.9 severely injured 0 crashes 0 non-severely injured</th>
<th>20 dead 70 severely injured 5421 crashes 1497 non-severely injured</th>
<th>13.4 dead 34.9 severely injured 3676 crashes 1015 non-severely injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>82476</td>
<td>82476</td>
<td>82476</td>
<td>82476</td>
</tr>
<tr>
<td>Tirewear</td>
<td>21290</td>
<td>21290</td>
<td>21290</td>
<td>21290</td>
</tr>
<tr>
<td>Environment</td>
<td>67480</td>
<td>67480</td>
<td>67480</td>
<td>67480</td>
</tr>
<tr>
<td>Lives</td>
<td>717024</td>
<td>647607</td>
<td>1841585</td>
<td>1168138</td>
</tr>
<tr>
<td>Time spent</td>
<td>-560658</td>
<td>-733592</td>
<td>1178992</td>
<td>563168</td>
</tr>
<tr>
<td>Net monetary benefit</td>
<td>4276</td>
<td>4276</td>
<td>4276</td>
<td>4276</td>
</tr>
<tr>
<td>Total</td>
<td>249411</td>
<td>7061</td>
<td>3113623</td>
<td>1824351</td>
</tr>
</tbody>
</table>

There is a significant difference in the results depending on the different assumptions in casualties but all the results lead to a positive total. The difference between maximum and minimum total net benefit values is close to 100 % or 3,100,000 SEK.

The sensitivity analysis shows a robust cost benefit analysis with no negative results for the net benefits from the SSSs.
6 Conclusion and future work

This analysis shows that the SSS project in Sweden generates a profit of more than one million SEK per system. This positive result is robust and needs very extreme values to change the sign. However, one cannot install an ever-increasing number of SSSs and expect the net benefit per SSS to be unchanging as the positive effects will decrease since the SSSs have to be put in places where the risk of an accident is not as great as in places where the existing SSSs are.

The profit from the SSSs could be increased by having the systems on all the time. If each system could find one speeding valid ticket each hour this would render an income of 17,000,000 SEK for each SSS and year. However, such a strategy would also result in an increase of personnel costs and vandalism. This is a political decision since one of the key considerations is the public acceptance of the SSS.

This work is based mainly on the statistics supplied by the Swedish Road Administration and SIKA. However, there are some gaps in the data, especially when it comes to material damage and minor injuries. Both of these are of a huge uncertainty but it is a thesis on its own just to cover this material. Also further investigations are needed on the behaviour of drivers in proximity of the SSS. The material in this thesis is limited.

The SSSs in Sweden today are only placed on the “national” roads. One can also imagine to place further SSSs, for instance, inside population centres. Speed enforcement is not the only type of enforcement that can be used; also red-light enforcement can be an interesting application.

One of the arguments that the police and NRA keeps coming back to is the risk of vandalism if the public does not accept the SSSs. However, no investigation has been made if there actually is an increase in vandalism if there is an increase in the number of fines or SSSs. It is, however, probable that an increasing acceptance will decrease the vandalism. Also an optimization needs to be made in regard to increasing the revenue by increasing the maximum amount of tickets while considering the associated personnel costs and increase in vandalism.
7 Appendices

Appendix A Environment

The environmental costs are only given for 88 and 91.5 km/h (Andersson, 2004) and the area of interest are between 71.27 and 75.98. One assumption is that in a sufficient small interval the quadratic behaviour of fuel consumption, etc can be approximated with a linear function.

Hence is the linear factor \( k \) found through:

\[
k = \frac{c_i - c_f}{v_i - v_f} \quad \text{(Eq. A1)}
\]

Where \( c_i \) and \( c_f \) is the initial and final cost. For instance, in the case of NOx it is 0.0341 and 0.0356 SEK/km respectively. \( v_i \) and \( v_f \) is the initial and final velocity 88 and 91.5 km/h. The linear constant \( m \) is found through:

\[
m = c_f - k \cdot v_f \quad \text{(Eq. A2)}
\]

This gives the following final equation for estimating the environmental cost at a certain speed:

\[
c = k \cdot v + m \quad \text{(Eq. A3)}
\]

Appendix B Savings of a life saver

From Vägverket only the number of severely injured (34.9) and deaths (13.4) annually avoided due to SSS is given which means that the number of non-severely injured as well as the number of damages has to be calculated. From Table 7 it can be read that, in general, the ratio over the year is 1.26 % dead, 19 % severely injured and 80% non-severely injured on all roads in non-rural areas. The ratio between the dead and the non-severely injured is:

\[
\frac{A_L}{A_L + A_s + A_{I,L}} \approx 1.26\% \quad \text{(Eq. A1)}
\]

Where \( A_L \) are the number of lives saved (difference death with and without SSSs in total) and that \( A_s \) severe injuries are prevented. \( A_{I,L} \) is the number of non-severely injured found by using equation A1:

\[
A_{I,L} = \frac{A_L}{1.26} - A_L - A_s = \frac{13.4 \cdot 100}{1.26} - 13.4 - 34.9 = 1,015 \quad \text{(Eq. A2)}
\]

By instead using the ratio between the number of severely injured and the number of non-severely injured the equation is:

\[
\frac{A_s}{A_L + A_s + A_{I,S}} \approx 19.0 \quad \text{(Eq. A3)}
\]
Where $A_{LS}$ is the number of non-severely injured from this equation. By rewriting equation A3 it leads to:

$$A_{LS} = \frac{A_S - A_L}{19.0} - 13.4 - 34.9 = 135 \text{ (Eq. A4)}$$

Since the number of non-severely injured ($A_{LS}$ and $A_{LL}$) vary quite dramatically as well as no specific statistics is given in the case of SSS, the lower number (135) calculated from the number of seriously injured is used, since this will give a lower estimate as well as this value can be considered more statistically valid.

According to the initial estimations from Väg och trafikforskningsinstitutet (2004) from before the initialization of the big ATK-project 20 lives should be saved and 70 severely injured should be avoided (Vägverket, 2008c). Note that this is not the same values as in the previous section. This would mean that 278 injuries would be prevented by using the lower estimate above but using the higher estimate 1,497 injuries would be avoided. The higher value is used in the sensitivity analysis.

When considering the decrease of speed in-between, an increase by 50% in avoided deaths and non-severely injured can be anticipated. According to Folksam (2008) there are 29,000 non-severely injured on 105,000 material damages for cars.

$$\frac{135 \times 105,000}{29,000} = 490 \text{ (Eq. A5)}$$

It means that 490 material damages could be avoided.

If we instead estimate 1,497 injuries (from 20 lives and 70 seriously injured avoided) avoided we get that

$$\frac{1,497 \times 105,000}{29,000} = 5,421 \text{ (Eq. A6)}$$

So the number of accidents would decrease by 5,421.

If we instead estimate 1,015 injuries (extrapolating from 13.4 deaths avoided) avoided we get that

$$\frac{1,015 \times 105,000}{29,000} = 3,676 \text{ (Eq. A7)}$$

The number of accidents would decrease by 3,676.

Note that these values from the insurance company Folksam (2008) differ dramatically from those published by SIKA (2009) based on damage reported to the police where there was 1.5 dead, severely injured or non-severely injured per damaged vehicle. By assuming 13.4 lives, 34.9 severely injured, 135 non-severely injured and 490 number of material damages avoided means that every year the lifesavers save 489,010,358 SEK/year or 717,024 SEK/SSS and year.
Appendix C The power model

The power model shows the correlation between how a change in speed will change the number of accidents etc. Denote speed by $V$, accidents by $Y$, and accident victims by $Z$. Furthermore, subscript by $0$ the values observed before a change in mean speed and by $1$ the values observed after a change in mean speed. The power model is then presented in Table 15.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fatal accidents</td>
<td>$Y_1 = \left(\frac{V_1}{V_0}\right)^4 Y_0$</td>
<td>$Y_1 \approx \left(\frac{V_1}{V_0}\right)^{3.6} Y_0$</td>
</tr>
<tr>
<td>Number of fatalities</td>
<td>$Z_1 = \left(\frac{V_1}{V_0}\right)^4 Y_0 + \left(\frac{V_1}{V_0}\right)^8 (Z_0 - Y_0)$</td>
<td>$Z_1 \approx \left(\frac{V_1}{V_0}\right)^{4.5} Z_0$</td>
</tr>
<tr>
<td>Number of fatal and serious injury accidents</td>
<td>$Y_1 = \left(\frac{V_1}{V_0}\right)^3 Y_0$</td>
<td>$Y_1 = \left(\frac{V_1}{V_0}\right)^{3.6} Y_0 + \left(\frac{V_1}{V_0}\right)^{2.4} Y_0$</td>
</tr>
<tr>
<td>Number of fatal or serious injuries</td>
<td>$Z_1 = \left(\frac{V_1}{V_0}\right)^3 Y_0 + \left(\frac{V_1}{V_0}\right)^6 (Z_0 - Y_0)$</td>
<td>$Z_1 \approx \left(\frac{V_1}{V_0}\right)^{4.5} Z_0 + \left(\frac{V_1}{V_0}\right)^3 Z_0$</td>
</tr>
<tr>
<td>Number of injury accidents (all)</td>
<td>$Y_1 = \left(\frac{V_1}{V_0}\right)^2 Y_0$</td>
<td>$Y_1 \approx \left(\frac{V_1}{V_0}\right)^2 Y_0$</td>
</tr>
<tr>
<td>Number of injured road users (all)</td>
<td>$Z_1 = \left(\frac{V_1}{V_0}\right)^2 Y_0 + \left(\frac{V_1}{V_0}\right)^4$</td>
<td>$Z_1 \approx \left(\frac{V_1}{V_0}\right)^{2.7} Z_0$</td>
</tr>
</tbody>
</table>

Elvik et al. (2004) also gave the model a good statistical basis, so for a larger system with the sufficient amount of statistical data the equations above can be considered to be reliable.

Appendix D Calculations on fuel consumption while passing an SSS

In order to get the total savings by a decreased speed one needs first to find the fuel consumption ($F$) as a function of speed ($v$). This is done by curve fitting to Fig. 2 and assuming a simple linear function.

$$F(v) = k \cdot v + m$$

Since any fuel saved $\Delta F$ while decelerating is neglected, the total fuel saved by decreasing speed is given by

$$\Delta F = F(v) \cdot d_1 - F(v_0) \cdot d_2 - Cons$$

Where $Cons$ is the fuel lost due to accelerating back from $v_0$ to $v$ (from 75.98 to 71.27 km/h) with mass $m$ (2,000 kg) and efficiency $\eta$. The behaviour of this acceleration was the one found in the Behaviour approaching an SSS section and from Fig. 2. That gives the distance $d_2$ which is equal 250m ($d_3 = d_1 - d_2 = 2,450 - 2,200 = 250$ m). The efficiency 30 % is the theoretical limit of a petrol engine (Boyle, 2003). Hence these calculations are an
overestimation. At the same time the power content \( (P_c) \) in petrol is 8,800 W (Nordling et al., 1994). So this gives that the fuel consumption is

\[
Cons = \frac{P}{P_c} \eta = \frac{1}{P_c} \frac{m(v^2 - v_0^2)}{2d_s} \eta = 0.32ml
\]

The saving due to installation \( \Delta F \) of SSS is approximately 3.0942 ml per passing vehicle and SSS (0.0031 L/SSS). There are 2,128,988 vehicles per SSS and year passing over 2.7 km near an SSS on average (Vägverket, 2008b) leading to a total decrease of 6,587.5 litres of fuel per SSS and year. According to Teknikens Värld (2009) the sale price of petrol was 12.52 SEK. The total money saved by decreased fuel consumption per SSS and year is:

\[
\text{Saved money} = \text{Saved fuel} \times \text{fuel prize} \times \text{no of vehicles per SSS and year} = 82,476
\]

**Appendix E Tirewear**

![EFFECT OF SPEED ON TIRE LIFE](image)

Fig. 27. High speed reduces the life of the tires.

Source: Fitzgerald, J. A. (1937)

**Appendix F Saving of tirewear reduction**

From Teknikens Värld (April 2000) it is known that one set of tires costs 4,000 SEK per vehicle and that they last approximately 40,000 km. This means that 1 km cost 0.1 SEK and a saving of 1.1% is a saving of 0.0011 SEK. It means that there is a saving of 0.01 SEK per vehicle and SSS.
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Environment, Transport and the Regions UK.


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