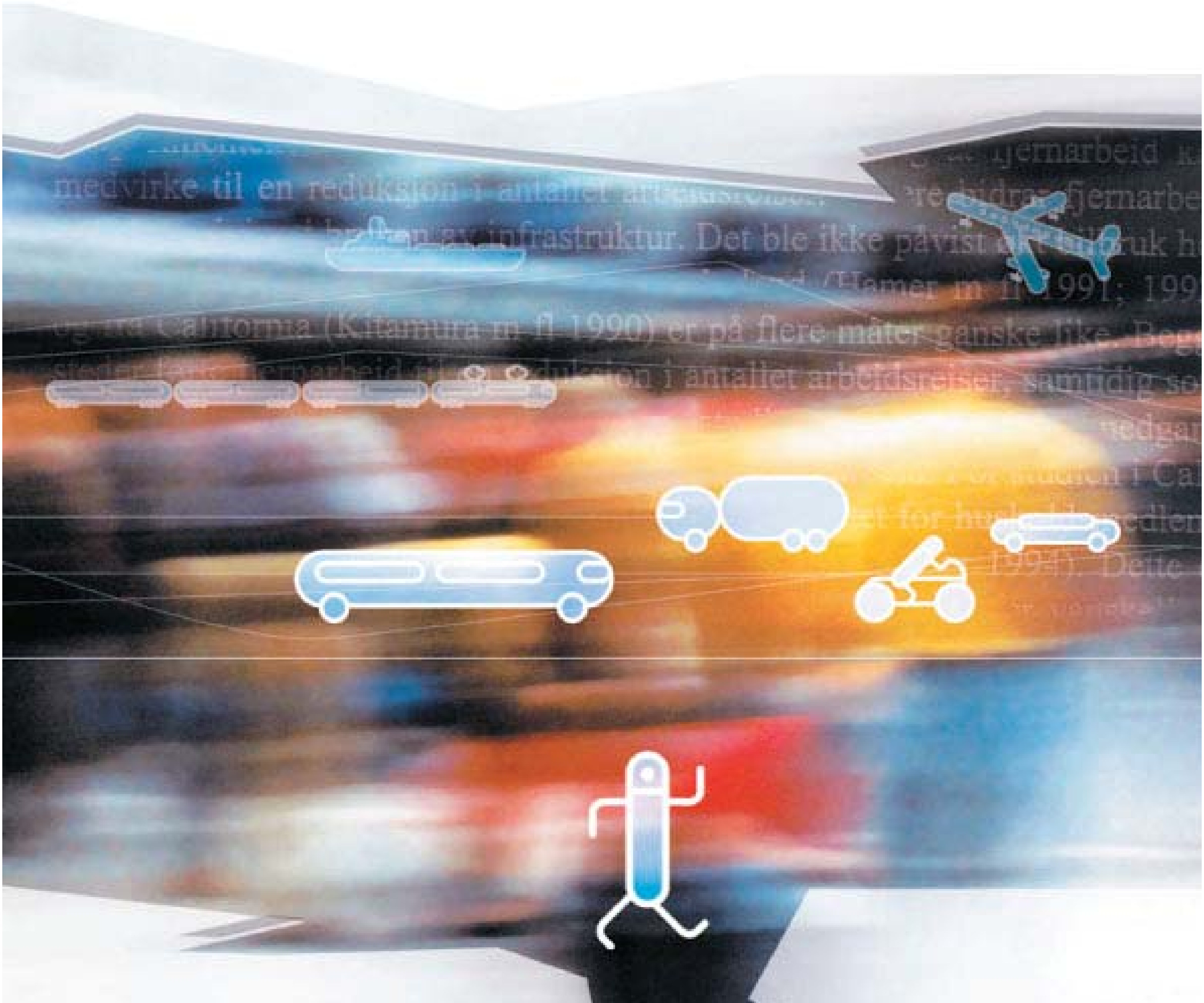
Institute of Transport Economics

An assessment of potential impacts on road safety of Traffic Warning Systems



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Peter Christensen

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Summary:
Traffic Warning Systems, a Norwegian company, has developed a radio based system for warning of specific traffic hazards. This report contains an assessment of the potential impacts of this system on road safety. It is estimated that the number of fatalities in Norway may be reduced by about 5 each year, and the total number of injured road users reduced by around 76 each year. In addition, about 266 property-damage-only accidents can be prevented each year. A cost-benefit analysis indicates that the value of these gains in road safety is greater than the costs of installing the warning system. This applies when all cars are equipped with the system. Less than 100% compliance will reduce benefits.

Tittel: En vurdering av mulige virkninger på trafikksikkerheten av traffic warning systems.

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Sammendrag:
Firmaet Traffic Warning Systems har utviklet et radiobasert system for varsling av bestemte trafikkfarer. Varsel er tenkt gitt i form av et blinkende lys på dashbordet. Denne rapporten inneholder en analyse av mulige virkninger på trafikksikkerheten av varslingssystemet. Det er beregnet at systemet kan redusere antallet drepte i trafikken med ca 5 per år og antallet skadde og drepte med ca 76 per år. I tillegg er det beregnet at ca 266 ulykker med kun materiell skade kan unngås hvert år. En nytte-kostnadsanalyse viser at nytten av systemet, regnet i kroner, overstiger kostnadene. Dette gjelder loikevel bare under forutsetning av at 100% av bilparken benytter systemet.

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Preface

Late detection of traffic hazards is one of the most common factors contributing to road accidents. If drivers are warned of traffic hazards, these hazards may be detected earlier and the number of accidents reduced. The company Traffic Warning Systems has developed a radio based system that can warn drivers of specific traffic hazards.

This report contains an assessment of the potential impacts on road safety of this system. Contact person for Traffic Warning Systems has been Harald Lindbäck. Project manager at the Institute of Transport Economics has been Rune Elvik. Peter Christensen performed the analyses of the official accident records that are presented in the report. The report has been written by Rune Elvik. Quality check was performed by Arild Ragnøy and Truls Vaa.

Oslo, December 2004
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TØI report 747/2004
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Summary:

An Assessment of the Potential Impacts on Road Safety of Traffic Warning Systems

Traffic Warning Systems is a Norwegian company which has developed a system for warning drivers of traffic hazards. The system is radio based. Warnings are given in the form of a flashing light on the dashboard. Different colours of the flashing light can be used to indicate different hazards. The range of the system is at least 500 metres. To benefit from the system, each motor vehicle must have a radio that can transmit and receive the warning signals. The system is activated by pushing a transmit button.

This report gives an assessment of the potential impacts on road safety of a universal application of this warning system by all motor vehicles in Norway. The types of traffic hazards the system is intended to cover are:

- Emergency vehicles on duty (ambulances, fire engines, police cars)
- Stationary or slow moving road works
- Trains approaching unprotected grade crossings with highways
- Disabled vehicles, left on the road shoulder in cases of engine failure, flat tire, or some other problem
- Pile up accidents, that is accidents in which three or more vehicles are involved.

The number of accidents that can be related directly to these traffic hazards was estimated on the basis of official Norwegian accident statistics, covering police reported injury accidents. The mean annual number (1995-1999) of injury accidents that can, in principle, be influenced by Traffic Warning Systems was estimated to about 600. Of these 520 were pile up accidents.

It is, however, unlikely that a warning system could prevent a large amount of pile up accidents. The dynamics of this type of accident is such that the pile up takes place very quickly, in most cases much too quickly for the driver to have the time to react to any warning. The only category of pile up accidents for which a warning system is likely to be effective, are those that happen under restricted sight conditions. Restricted sight conditions include darkness on unlit roads, and poor sight conditions due to fog, rain or snow. When sight conditions are restricted, it is conceivable that the third, fourth, and so on vehicle arriving at an accident scene fails to detect the accident in time to avoid becoming involved in it. A warning could then be effective.

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If pile up accidents in restricted sight conditions are regarded as the only type of pile up accident that can be prevented by a warning system, the annual number of injury accidents that can be affected by Traffic Warning Systems comes to 115. In these accidents 213 people are killed or injured.

It has been estimated that, if all motor vehicles (except mopeds, snow scooters and motorcycles) in Norway had the warning system, the following number of injured road users could be prevented each year:

- 5 fatal injuries
- 2 very serious injuries
- 8 serious injuries
- 60 slight injuries

The total comes to 76 killed or injured road users per year. In addition, it was estimated that about 266 property-damage-only accidents can be prevented each year.

The possibility of road user behavioural adaptation to the system, offsetting in part or in full the estimated safety benefits, is discussed. One form of behavioural adaptation could be that the system is ignored if the warnings come on too frequently, for no immediately apparent reason. It is concluded that although behavioural adaptation cannot be ruled out, it is very improbable that any changes in behaviour induced by the system would completely eliminate the estimated gains in safety.

A cost-benefit analysis of introducing the system for all motor vehicles in Norway has been performed. The costs of installing the system in all motor vehicles come around 890 million NOK (1 NOK = 0.1208 EURO). The best estimate of the benefits, converted to monetary terms, is about 1,150 million NOK. This estimate relies on official estimates of road accident costs in Norway. Benefits are greater than costs. The system is based on supplying electricity by means of a battery. If many vehicle owners fail to change batteries on time, the benefits of the system may become smaller over time. The estimates above presume 100% compliance with the system. In practice it may prove difficult to reach such a high level of compliance.

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Sammendrag:

En vurdering av mulige virkninger på trafikksikkerheten av Traffic Warning Systems

Traffic Warning Systems er et norsk firma som har utviklet et radiobasert system for varsling av bestemte trafikkfarer. Varsel er tenkt gitt i form av et blinkende lys på dashbordet eller instrumentpanelet. Ulike farger på lyset kan benyttes for ulike typer trafikkfarer. For å kunne benytte systemet, må et kjøretøy være utstyrt med en egen radio som kan sende og motta varselsignaler. Systemets rekkevidde er minst 500 meter.

Denne rapporten inneholder en vurdering av mulige virkninger på trafikksikkerheten av dette varslingssystemet, forutsatt at det er montert i alle motorkjøretøy. De trafikkfarer som i første rekke tenkes dekket av systemet er:

- Utrykningskjøretøy under utrykning
- Vegarbeider (stasjonære eller svært langsomt bevegelige)
- Tog som nærmer seg usikrede planoverganger med veg
- Kjøretøy som er hensatt på vegskulderen på grunn av motorstopp, punktering, eller andre problemer
- Ulykker som utvikler seg til kjedekollisjoner, der først to biler kolliderer. Deretter blir en tredje, en fjerde, og så videre bil innblandet i ulykken.

På grunnlag av den offisielle ulykkesstatistikken er det årlige antallet ulykker som kan knyttes direkte til disse trafikkfarene beregnet. Det var i årene 1995-1999 i gjennomsnitt ca 600 personskadeulykker som i prinsippet kan påvirkes av Traffic Warning Systems. Av disse var ca 520 kjedekollisjoner der minst tre kjøretøy var innblandet. Mopeder, motorsykler og snøscootere forutsettes ikke å ha systemet.

På grunnlag av generell kunnskap om hendelsesforløpet ved kjedekollisjoner, anses det som lite sannsynlig at et varslingssystem kan påvirke slike ulykker annet enn i spesielle tilfeller. Grunnen til det, er at slike ulykker som regel skjer så fort at førerne uansett ikke har tid til å reagere på noe varsel. Den eneste gruppen av kjedekollisjoner hvor det ble ansett som mulig at et varslingssystem kan ha betydning, er kjedekollisjoner som skjer ved nedsatt sikt. Nedsatt sikt omfatter mørke på ubelyst veg, nedsatt sikt på grunn av nedbør og nedsatt sikt på grunn av tåke. Når sikten er nedsatt, er det tenkelig at den tredje, fjerde, og så videre bilen som ankommer ulykkesstedet ikke oppdager ulykken i tide og derfor blir innblandet i en kjedekollisjon. Et varsel om ulykken vil da kunne virke.

Dersom bare kjedekollisjoner som skjer ved nedsatt sikt regnes som aktuelle, blir det årlige antallet personskadeulykker som kan påvirkes av Traffic Warning

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Systems ca 115. I disse ulykkene blir i gjennomsnitt 213 mennesker skadet eller drept.

Det er beregnet at dersom alle biler og traktorer hadde Traffic Warning Systems, kan man redusere det årlige antallet skadede og drepte i trafikken med følgende antall (avrundet til nærmeste hele tall):

- 5 drepte
- 2 meget alvorlig skadde
- 8 alvorlig skadde
- 60 lettere skadde

Til sammen er dette 76 personer. I tillegg er det beregnet at ca 266 ulykker med kun materielle skader kan forhindres hvert år.

Muligheten for atferdstilpasning til systemet, som kan redusere de beregnede virkninger på trafikksikkerheten er drøftet. Slik atferdstilpasning kan for eksempel være at førerne ignorerer systemet hvis varsel gis altfor ofte, uten noen åpenbar grunn. Det ble konkludert med at atferdstilpasning som helt eliminerer de beregnede sikkerhetsgevinster må betraktes som lite sannsynlig.

Det er gjort en nytte-kostnadsanalyse av å innføre Traffic Warning Systems på alle biler og traktorer i Norge. Kostnadene ved dette er beregnet til omlag 890 millioner kroner. Beste anslag på nytten, basert på de ulykkeskostnader vegmyndighetene bruker i konsekvensanalyser av vegprosjekter, er nær 1150 millioner kroner. Nytten er følgelig større enn kostnadene. Systemet forutsettes drevet av et batteri, som bør skiftes årlig. Dersom ikke alle gjør dette, kan nytten av systemet over tid bli redusert.

Beregningene over forutsetter at 100% av biler og traktorer i Norge har systemet. Dette er ikke realistisk uten at systemet påbys ved lov.

1 Introduction

Failure to detect a traffic hazard in time is one of the most common factors contributing to road accidents (Rumar 1985, 1990). The failure to detect a traffic hazard may occur for a number of reasons. The hazard may be hidden from view, it may be difficult to locate precisely, or it may behave in an unpredictable way, which violates driver expectations. Irrespective of why a traffic hazard is not detected in time, measures that may assist drivers in detecting traffic hazards have been shown to reduce the number of road accidents. Measures enhancing visibility, such as road lighting or daytime running lights on cars, are important examples of this kind of road safety measure.

This report presents an assessment of the potential for improving road safety by means of a radio based system, labelled Traffic Warning Systems. The system will function as an in-car “warning triangle”. Warnings of nearby traffic hazards are given in the form of a flashing signal, which is activated by a radio transmitter installed in motor vehicles. The full potential of such a system in warning of traffic hazards can only be realised if all motor vehicles are equipped with a radio that can both transmit and receive the warning signals. However, even a more restricted use of the system may help some drivers to detect certain traffic hazards that they might otherwise not have detected. A short description of the system is given in the next chapter.

The objective of this report is to assess the potential impacts on road safety of introducing Traffic Warning Systems in all motor vehicles. The following questions are examined:

- Which types of road accidents can a universal application of Traffic Warning Systems be expected to affect?
- How many accidents of the types that can be affected occur annually in Norway, especially accidents involving personal injury?
- How great an effect in reducing affected accidents can Traffic Warning Systems be expected to have?
- Can Traffic Warning Systems have any additional, favourable effects on traffic operations?
- Can Traffic Warning Systems have any potentially adverse effects on accidents, in addition to the intended effects of the system?
- What are the costs and benefits in monetary terms of a universal application of Traffic Warning Systems?

2 A Short Description of Traffic Warning Systems

Traffic Warning Systems is a radio based system designed to warn drivers of specific traffic hazards. Each radio unit will consist of a transmitter and a receiver. The transmitter sends a warning signal, which can be picked up in an area with a radius of about 500 metres from the transmitter. The receiver reads the signal and displays the warning on the dashboard, or instrument panel, in the form of a flashing light. It is assumed that the receiver is on at all times. The transmitter is switched on as the need arises. For a detailed technical description of the system, see the reports by Pleym (2000A, 2000B – the reports are confidential).

The system is intended to give warnings only of a few traffic hazards. More specifically, the following applications of the system have so far been envisaged:

- Warning of emergency vehicles on duty, that is ambulances, fire engines or police cars on emergency missions. A flashing blue warning signal will indicate the presence of an emergency vehicle on duty in the vicinity. Emergency vehicles on duty are assumed to turn on the transmitter.
- Warning of road works, especially those that involve lane closures or restrictions. A flashing yellow signal will indicate road works on a road which is open to traffic while the works are in progress. Machines used in road works will also turn on the transmitter.
- Warning of a train approaching an unprotected at-grade crossing with a road. A flashing red signal will indicate an approaching train. Trains will run with the transmitter on.
- Warning of disabled vehicles, parked or abandoned on the roadside or shoulder of the road in an emergency, such as engine failure, flat tire or some other mechanical problem. A flashing red signal will warn of the presence of a disabled vehicle. When a vehicle becomes disabled, the driver is assumed to turn on the transmitter.
- Warning of a road accident, in which it is assumed that the transmitter will be activated automatically by a unit measuring the force of deceleration in the accident. If the accident is not severe enough to activate the system, it is assumed that it will be turned on manually. A flashing red signal will warn of an accident.

By restricting the system to these traffic hazards, it is hoped that one will avoid the problem of getting too frequent warnings. A system giving very frequent warnings may be disregarded by drivers, as they learn that many of the warnings are not relevant to them.

To prevent abuse of the system by ordinary motorists, a loud and annoying noise signal will be produced inside the car if the warning signal is switched on. It is assumed that this signal is a minor problem if a real emergency has occurred, but will deter drivers from switching on the system when there is no emergency (that is no accident or mechanical breakdown).

It will be noted that a flashing red signal is used for three of the five cases mentioned above. Two of these – that of an accident and a disabled vehicle – closely resemble each other. It is rather unlikely that the third case, that of a train approaching an unprotected at-grade crossing, can be confused with the other two cases in which a red signal is given. This could happen only in case there has been an accident, or an event disabling a vehicle, very close to an unprotected railway crossing, while at the same time no train is approaching this crossing. A driver who intends to cross the railway may then misinterpret the signal as warning of a train, and wait in vain for the train to pass. However, such an event must be regarded as rather unlikely, although it is not possible to quantify its likelihood of happening.

The range of the system has been tested in selected situations. Table 1 summarises the results of these tests.

Table 1: Range of Traffic Warning Systems in selected situations.

Situation tested	**Minimum range obtained (metres)**
1: Straight line of sight, flat terrain	3,000-4,000
2: Low rise buildings along the road	200-1,000
3: Straight line of sight, across hilltop	400-500
4: Curved road around hilltop	400-500
5: Road tunnel	1,500-2,500

Source: Pleym 2000A, 2000B

The minimum range obtained in the situations that were tested was around 200 metres. This was in an urban area. A range of 200 metres corresponds to a warning time of about 14 seconds at a speed on 50 km/h. The other scenarios are more likely to be found outside built-up areas, where the speed of traffic is higher. A range of 400 metres corresponds to a warning time of about 18 seconds at a speed of 80 km/h.

In most cases, it is reasonable to assume that warning times of more than 10 seconds are sufficient for the driver to react to the warning. Typical reaction times for car drivers are in the range of 1-5 seconds (Elvik and Vaa 1990).

3 Road Accidents that may be affected by Traffic Warning Systems

3.1 Vision Zero for Road Accidents

Vision Zero is the official basis for road safety policy in Norway. In the recent Parliamentary report on the national transport plan for the years 2002-2011, the Ministry of Transport states (St. meld. 46, 1999-2000, page 140):

"The basis for road safety policy is a vision of a transport system in which there are no accidents that result in deaths or permanent injuries. As a consequence of this vision, road safety measures will be introduced to reduce the number of fatal or serious accidents and to reduce accident severity."

Vision Zero is intended to inspire to the development of new road safety measures. It is in the spirit of this vision that Traffic Warning Systems has been developed.

3.2 Types of Accidents that may be affected by Traffic Warning Systems

Based on the description of the types of traffic hazards covered by Traffic Warning Systems, it is assumed that the following types of road accidents can be affected by the system:

- Accidents in which emergency vehicles on duty are involved, except for single vehicle accidents involving emergency vehicles, and accidents in which pedestrians or cyclists are struck by emergency vehicles. These accidents will be referred to as "emergency vehicle accidents".
- Accidents in which stationary or slow moving cars, trucks or machines used in road works are involved, crashing with other motor vehicles. These accidents will be referred to as "road works accidents".
- Accidents involving trains and motor vehicles at unprotected at-grade crossings between highways and railways. These accidents will be referred to as "railway crossing accidents".
- Accidents in which a disabled vehicle is struck by another motor vehicle, especially outside built-up areas. These accidents will be referred to as "disabled vehicle accidents".
- Accidents in which a third, fourth, and so on, motor vehicle crashes into two other motor vehicles that have crashed earlier. These accidents will be referred to as "pile up accidents".

To estimate the expected annual number of accidents in each of these categories, the official road accident statistics for Norway was examined for the years 1995 through 1999. It was decided to use five years of accident data in order to smooth out random fluctuations from year to year, and to be able to detect if there are any long term trends in the number of accidents.

The official road accident statistics for Norway contains police reported injury accidents only. Accidents resulting in property-damage-only are not included. Moreover, the reporting of injury accidents is known to be incomplete (Elvik and Mysen 1999). The reporting level for injury accidents in which a motor vehicle is involved is close to 50%. Fatal accidents are always reported, and the reporting level for accidents resulting in serious injury is around 70%. Despite the incompleteness of reporting, the official accident statistics is the most detailed statistics on road accidents which is available in Norway. It is in fact the only source in which the types of accidents that can be affected by Traffic Warning Systems can be identified with reasonable accuracy.

3.3 Number of Accidents in Target Groups according to Official Road Accident Statistics for Norway

Table 2 shows the recorded number of accidents with personal injury in each of the five categories identified above, according to official Norwegian accident statistics. Based on a preliminary inspection of the data, it was decided to omit accidents in which mopeds, snow scooters or motorcycles are involved. There are few of these accidents. It was therefore judged that requiring all mopeds, snow scooters and motorcycles to have the warning system would be disproportionately costly. The number of accidents involving mopeds, snow scooters and motorcycles is discussed below.

Table 2 shows that the largest group of accidents that may, in principle, be affected by Traffic Warning Systems, is pile up accidents. There are several hundred of these accidents each year. The total number of injured road users in pile up accidents is slightly more than 1,000 per year, which is about 8% of the total number of people injured in road accidents reported to the police (around 12,000 per year). The majority of the pile up accidents are rear end collisions.

Compared to pile up accidents, the other categories of accidents that may be affected by Traffic Warning Systems are rather small. The number of accidents per year is less than 50. For category D, disabled vehicle accidents, the number of accidents per year is around 30. It should be noted, however, that accidents involving disabled vehicles cannot be identified very precisely in official accident statistics. The closest approximation that was possible, was statistics showing accidents involving parked vehicles outside built-up areas.

Table 2: Recorded number of injury accidents in target groups for Traffic Warning Systems

		Number of road users killed or injured				
Year	**Number of accidents**	**Killed**	**Very seriously injured**	**Seriously injured**	**Slightly injured**	**Total number of killed or injured**
Category A: Emergency vehicle accidents						
1995	14	1	2	0	20	23
1996	6	0	0	0	8	8
1997	12	1	0	1	15	17
1998	21	1	0	2	48	51
1999	6	0	0	1	9	10
Mean	11.8	0.6	0.4	0.8	20.0	21.8
Category B. Road works accidents						
1995	25	2	1	7	44	54
1996	44	3	3	8	49	63
1997	33	0	1	1	36	38
1998	29	2	1	3	40	46
1999	37	5	3	5	49	62
Mean	33.6	2.4	1.8	4.8	43.6	52.6
Category C: Railway crossing accidents						
1995	4	0	0	2	3	5
1996	5	0	0	1	5	6
1997	2	0	0	0	2	2
1998	5	6	0	0	33	39
1999	5	1	0	0	4	5
Mean	4.2	1.4	0.0	0.6	9.4	11.4
Category D: Disabled vehicle accidents						
1995	32	0	1	6	44	51
1996	32	3	0	10	42	55
1997	31	0	0	4	37	41
1998	26	2	1	1	36	40
1999	32	0	0	2	39	41
Mean	30.6	1.0	0.4	4.6	39.6	45.6
Category E: Pile up accidents						
1995	478	16	16	59	893	984
1996	544	21	11	64	1051	1147
1997	501	28	3	45	900	976
1998	520	22	8	71	989	1090
1999	552	23	13	53	1038	1127
Mean	519.0	22.0	10.2	58.4	974.2	1064.8

Source: TØI report 747/2004

Similar comments apply to category B, road works accidents. These accidents cannot be identified precisely in official road accident statistics. The closest approximation possible was accidents involving trucks with a “mechanical” trailer. This category of vehicles does not include ordinary truck and trailer combinations.

Finally, the annual number of accidents in category A, emergency vehicles on duty, and category C, railway grade crossings is very low, in most cases less than 20. However, the severity of these accidents is comparatively high, as indicated by a high proportion of killed or seriously injured accident victims (18% for railway crossing accidents).

The mean annual number of injury accidents in the target groups is about 600, of which around 520 are pile up accidents. On the average nearly 27 people are killed, around 13 very seriously injured, around 69 seriously injured and around 1,087 slightly injured each year in the target groups of accidents.

Table 3 shows the contribution of accidents involving mopeds, snow scooters and motorcycles to the number of target accidents.

Table 3: Contribution of accidents involving mopeds, snow scooters and motorcycles to target accidents. Annual mean values

	Mean annual number of police reported injury accidents	
Target group of accidents	**Excluding mopeds, snow scooters and motorcycles**	**Including mopeds, snow scooters and motorcycles**
A. Emergency vehicles	11.8	13.6
B: Road works	33.6	35.8
C. Railway grade crossings	4.2	4.2
D: Disabled vehicles	30.6	33.2
E: Pile up accidents	519.0	543.2
Total	599.2	630.0

Source: TØI report 747/2004

It is seen, that including accidents involving mopeds, snow scooters and motorcycles would increase the annual number of target accidents from 599 to 630, an increase of about 5%. However, mopeds, snow scooters and motorcycles make up 9% of all registered motor vehicles in Norway. In the subsequent analyses, accidents involving mopeds, snow scooters and motorcycles have been excluded.

Preliminary statistics show that the number of fatal accidents at railway grade crossings has increased in the year 2000. Eight fatalities have been recorded so far. Compared to the earlier years, the current year appears to have been abnormally bad for railway crossing accidents. Since final statistics for the year 2000 are not yet available, statistics for the years 1995-1999 have been used.

3.4 A Comparison of Official Road Accident Statistics and other Sources of Data

For some of the accidents listed in Table 2, it is possible to compare official road accident statistics to other sources of data. In particular, railway grade crossing accidents are recorded by the rail track administration. Table 4 compares the number of accidents and injured road users recorded by the rail track administration to the numbers recorded in official road accident statistics.

These two sources of data appear to agree quite well. In general, the number of accidents recorded by the rail track administration tends to be higher than the number of accidents recorded in official road accident statistics, but the number of victims (people killed or injured) tends to be lower or the same. An advantage of the statistics kept by the rail track administration, is that it records the type of grade crossing. It is thus possible to identify unprotected at-grade crossings, that is crossings where there are no signals or barriers warning of an approaching train.

Table 4: Railway grade crossing accidents recorded in official road accident statistics and by the rail track administration (Jernbaneverket)

	Source of accident data			
	Official road accident statistics		Statistics kept by rail track administration	
Year	**Accidents**	**Victims**	**Accidents**	**Victims**
1995	4	5	4	6
1996	5	6	9	3
1997	2	2	9	2
1998	5	39	12	9
1999	5	5	17	7
Mean	4.2	11.4	10.2	5.4

Source: TØI report 747/2004

Another category of accidents for which a second source of data can be found, is accidents at road works. The annual report of the Public Roads Administration provides data on these accidents. Table 5 presents the data from these two sources.

Table 5: Accidents at road works recorded in official road accident statistics and by the Public Roads Administration (Vegdirektoratet)

	Source of accident data			
	Official road accident statistics		Statistics kept by public roads administration	
Year	**Total number of injured**	**Number of killed**	**Total number of injured**	**Number of killed**
1995	58	2	173	1
1996	75	3	204	0
1997	46	1	181	0
1998	56	3	201	3
1999	71	6	158	5

Source: TØI report 747/2004

The two sets of figures are not comparable. The statistics kept by the Public Roads Administration includes all injuries sustained by employees of the national highway agency, irrespective of whether these occurred in road traffic accidents or other kinds of work related accidents. The official road accident statistics are, on the other hand, confined to road traffic accidents that occur on roads open to the public. Despite these differences, the two sources of data agree fairly well with respect to the number of fatal injuries. There are large differences with respect to the total number of injuries. These differences are probably attributable to the fact that many of the accidents recorded by the Public Roads Administration are likely to have occurred outside public roads, for example in road construction areas, asphalt plants, machine workshops, and so on.

In the following analysis, figures from the official road accident statistics will be used throughout.

4 Potential Effects on Road Accidents of Traffic Warning Systems

4.1 Potential Effects on Road Accidents of Traffic Warning Systems – Theoretical Discussion

As noted in the introduction, late detection of traffic hazards is an important contributing factor to road accidents. One would therefore expect, everything else equal, that if traffic hazards can be detected earlier, accidents caused by late detection of these hazards can be prevented. In practice, however, estimating the number of accidents that can be prevented by an earlier detection of traffic hazards is difficult. It involves a number of problems:

- Although there is reason to believe that late detection of traffic hazards contributes to many accidents, it is not known exactly how many accidents that can be attributed primarily to this risk factor. It is, in other words, impossible to quantify the contribution to accidents of late detection of traffic hazards in terms of attributable risk, or some other numerical measure.
- Even if a traffic hazard is detected early, it may still be impossible to avoid the accident, if, for example, the driver is unable to take the appropriate evasive action. The driver may "see the accident coming", but still be unable to prevent it.
- Drivers tend to adapt their behaviour to technical improvements in vehicles, a point which will be discussed more extensively in the next chapter. If drivers come to rely heavily on a technical system to warn them of traffic hazards, they may pay less attention to such hazards than they would do if left to their own devices. This means that, although some hazards may be detected earlier, the driver may take longer to react to them, because he or she has reduced the level of attention paid to traffic hazards.
- Predicting the effects of new technology designed to reduce accidents is always difficult. One has to rely on a combination of theoretical considerations, effects of similar technologies, or analogies to other accident prevention measures. Moreover, one must assume 100% compliance with the system, which may not be very realistic.

Despite these difficulties, one should always try to estimate the effects of a new technology designed to prevent accidents. Unless an attempt is made to estimate these effects, there is no basis for deciding whether or not introducing the technology is a good idea. One should always bear in mind, however, that the effects estimated, are *potential effects* only. Actual effects can only be determined once the technology has been introduced and used for some time.

4.2 Potential Effects on Road Accidents of Traffic Warning Systems – A Preliminary Quantification

4.2.1 Category A: Emergency vehicle accidents

Emergency vehicles are painted in bright colours, are equipped with warning lights, and often use loud sound signals when on duty. Despite all these safety precautions, emergency vehicles are surprisingly often not detected in time by car drivers. The Traffic Safety Handbook (Elvik, Mysen and Vaa 1997) quotes a Swedish study, in which the percentage of car drivers who were involved in accidents with emergency vehicles, and who did not notice either a) flashing warning lights, b) sound signal, or c) the vehicle itself, was determined. Table 6 reproduces the results of this study.

Table 6: Percent of accident involved car drivers who did not notice flashing lights, sound signals or the vehicle in crashes with emergency vehicles.

	Percent who did not detect		
Emergency vehicle	**Flashing lights**	**Sound signals**	**Vehicle**
Ambulance (102 accidents)	41	39	31
Fire engine (39 accidents)	39	40	14
Police car (157 accidents)	49	47	44

Source: Elvik, Mysen and Vaa 1997

In general, around 40-50% did not notice either the vehicle, sound signals or flashing lights.

The assumption will be made, that Traffic Warning Systems can prevent the accidents in which at least one of the traditional warning systems used by emergency vehicles was not noticed. The percentage of accidents that can be prevented is equal to the mean of the percentages for "did not notice" given in Table 6 for each type of emergency vehicle. This percentage comes to 38. To simplify estimation, the assumption is made that:

It will be assumed that Traffic Warning Systems has the potential to prevent 40% of all injury accidents involving emergency vehicles on duty.

4.2.2 Category B: Road works accidents

There are two approaches to trying to determine the potential impacts of Traffic Warning Systems on accidents at road works sites. One approach is to assume that the system can eliminate the added risk of accident associated with road works. According to the Traffic Safety Handbook (Elvik, Mysen and Vaa 1997), road works increase the risk of injury accidents by about 10%. This means that vehicles passing road works sites have a 10% higher injury accident rate per vehicle kilometre of driving than vehicles passing the same sites when no road works are in progress. Eliminating this increase in accident risk therefore corresponds to an accident reduction of about 10%.

The other approach to estimating the potential impacts of Traffic Warning Systems, is by analogy to the impacts of other types of warning devices that have been applied at road works sites. The effects on accidents of these warning devices, which include warning flags, road markings, temporary speed limits, and closing of traffic lanes, vary from about 15% accident reduction to about 40% accident reduction.

It is not unreasonable to assume that Traffic Warning Systems may have a somewhat smaller impact at road works sites than with respect to accidents involving emergency vehicles. The reason for assuming this, is that there are often temporary traffic control systems and warning devices operating at road works sites, which many drivers will notice. These systems have already warned the driver of road works. An additional warning device, such as Traffic Warning Systems, is likely to be less effective in this case, than in cases where no other warning has already been given. This line of reasoning is admittedly hypothetical, but is indirectly supported by the studies that have evaluated the effects on accidents of traditional warning devices at road works sites.

It will be assumed that Traffic Warning Systems has the potential to prevent 20% of all injury accidents at road works sites.

4.2.3 Category C: Railway at-grade crossing accidents

Although no statistics can confirm it, it is reasonable to assume that many of the accidents at unprotected at-grade highway-railway crossings occur because drivers did not expect the train to come. They were taken totally by surprise by the train suddenly appearing out of nowhere. This problem is likely to be particularly common at grade crossings located where the railway is in a curve, which restricts the driver’s line of sight.

The assumption will be made, that Traffic Warning Systems can reduce the number of accidents at unprotected at-grade crossings by 50%. This effect is identical to the one found for flashing lights and sound signals. Flashing lights and sound signals are analogous to Traffic Warning Systems in that they warn the driver of an approaching train, but does not physically prevent the driver from crossing the railway. Only automatic barriers can physically prevent the driver from crossing the railway, but such barriers are too expensive to install at unprotected crossings that serve just a few vehicles per day.

It will be assumed that Traffic Warning Systems has the potential to prevent 50% of all injury accidents at unprotected at-grade crossings between roads and railways.

4.2.4 Category D: Disabled vehicle accidents

It is difficult to find a good basis for estimating the potential impacts of Traffic Warning Systems on accidents involving disabled vehicles. In the first place, the exact number of such vehicles struck by other vehicles is not known. The statistics given in chapter 3 was just an approximation, as close as the accident record permits. In the second place, no studies have been found that have evaluated the effectiveness of any system resembling Traffic Warning Systems in preventing accidents involving disabled vehicles. In this case, a choice has been made to rely on the results of an in-depth study of factors contributing to road accidents (Treat et al 1979). According to this study, human factors, in particular human errors, figures prominently among the immediate causes of accidents. “Recognition errors” (failure to observe correctly) was judged be involved as a contributing factor in 41% of the accidents. Based on this, the assumption has been made that:

It will be assumed that Traffic Warning Systems has the potential to prevent 40% of all injury accidents involving disabled vehicles.

4.2.5 Category E: Pile up accidents

The number of pile up accidents was, as shown in chapter 3, several hundred per year, a surprisingly high number. The majority of these accidents were rear end collisions, in which three or more cars are involved. Official accident statistics does not state whether the cars involved in pile up crashes all crashed at once, or whether the first two cars crashed some time before the third, fourth, and so on car became involved in the accident. In the majority of cases, however, it is reasonable to assume that the pile up takes place so quickly that no warning system could have prevented it. This is particularly true of rear end collisions.

Evans (1991) gives a very instructive description of the dynamics of a rear end pile up crash. Somewhat counter intuitively, such pile up accidents often start from the rear, not from the front. It is often *not* the case that the second car in a platoon first crashes into the first car, then the third car crashes into the second, the fourth car into the third, and so on, in that order. Rather, things happen the other way around. In a platoon of, say, four cars, the fourth car first crashes into the third. The force of the crash then pushes the third car into the second, which is in turn pushed into the first. In other words, the pile up starts from the rear, not from the front.

To understand why this can be the case, consider Figure 1. It pictures four cars travelling in a platoon at 80 km/h, with a headway of two seconds. This situation is fairly common during the week end on some heavily trafficked two lane roads in Norway. The horizontal axis shows time elapsed in seconds. The vertical axis shows distance travelled in metres. This distance is 22.2 metres per second at 80 km/h and 11.1 metres per second at 40 km/h. The first car brakes to a speed of 40 km/h, shown by the shift in the slope of the line for the first car. It then further slows down to 20 km/h. The driver of the second car takes almost three seconds to react to this, but is nevertheless able to brake gently and avoid hitting the first car. However, the distance between the cars narrows from 44 metres to 11 metres. The driver of the third car has less time to react and brakes more heavily, as indicated by the sharper turn of the curve for the third car. It is assumed, however, that even the driver of the third car manages to reduce speed in time to avoid an accident. The forward distance to the second car crumbles to 5.5 metres. The driver of the fourth car is, however, unable to brake in time and crashes into the third car.

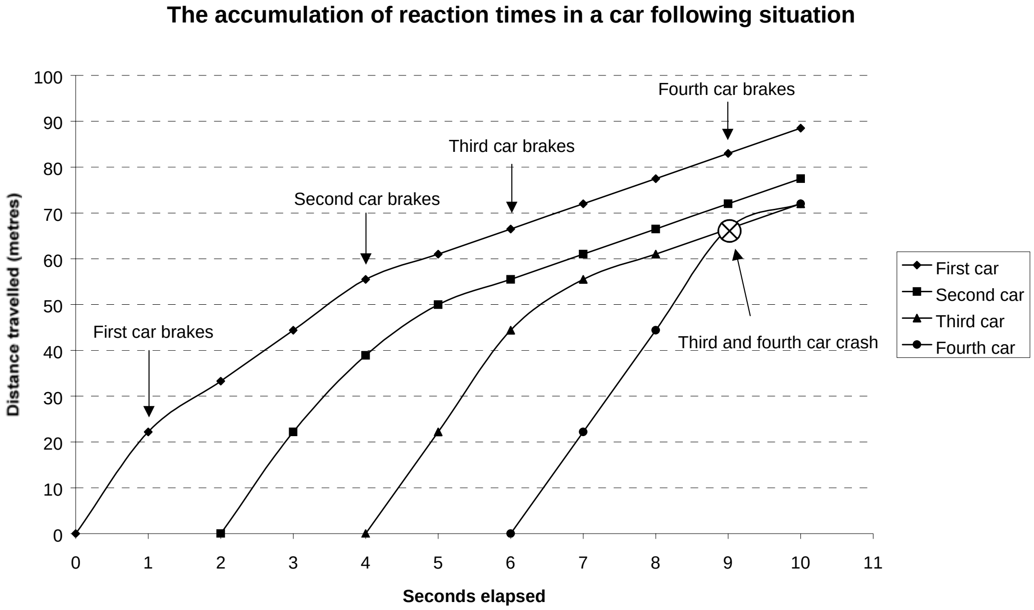

Figure 1: The dynamics of a rear end pile up crash. Simplified diagrammatic exposition, based on Evans 1991.

This accumulation of driver reaction times in a platoon may be exacerbated if drivers try to compensate for it by braking harder once they notice the critical situation. By braking harder, a driver makes the task for those coming behind him more difficult. A driver braking very hard may well be able to stop in time, only to be hit in the rear by the driver following immediately behind him in the platoon.

In view of this, it will be assumed that Traffic Warning Systems cannot prevent rear end pile up crashes. It is likely that most of these pile ups happen so quickly that there is simply not enough time to react, irrespective of whether or not a warning is given.

It seems likely that the same point of view applies to most other pile up crashes, at least those that occur when sight conditions are good. The only group of pile up accidents that can be prevented by Traffic Warning Systems, are those in which the third or fourth car arrive at the accident scene so much later than the first two cars as to have the time to react to a warning signal. Exactly how many accidents of this kind there are, cannot be known on the basis of official accident statistics. As an approximation, it will be assumed that pile up accidents, except rear end accidents, that occur during restricted sight conditions, can be affected by Traffic Warning Systems. When sight conditions are restricted, like in fog, it may be more likely that cars arriving at an accident scene some time after the accident occurred, will detect it too late to avoid getting involved in it. Restricted sight conditions includes:

- Darkness on unlit roads
- Reduced sight conditions caused by rain or snow
- Reduced sight conditions caused by fog
- Reduced sight conditions, no specific cause stated

In addition to pile up accidents in restricted sight conditions, accidents on slippery road surfaces were considered. Slippery road surfaces adversely affect road safety, chiefly by making it more difficult to stop. One might therefore think that a system warning of accidents would be particularly useful on slippery roads. On the other hand, unless warnings are given earlier on slippery roads than on normal road surfaces, there is less time to stop. While slipperiness itself increases the need of early warnings, there is no reason to believe that a warning system would be more effective on slippery roads than otherwise. On the contrary, the reduced amount of road surface friction available would, if anything, make a system less effective on slippery roads than on road surfaces with normal friction. In the following analysis, an effect of Traffic Warning Systems on pile up accidents has therefore been assumed to apply to restricted sight conditions only.

The annual number (1995-1999) of pile up injury accidents, except rear end pile ups, that occurred in restricted sight conditions is shown in table 7.

Table 7: Annual number of pile up accidents assumed to be affected by Traffic Warning Systems

		Number of road users killed or injured				
Year	**Number of accidents**	**Killed**	**Very seriously injured**	**Seriously injured**	**Slightly injured**	**Total number of killed or injured**
1995	35	1	6	14	65	86
1996	38	6	2	12	66	86
1997	34	6	1	11	63	81
1998	32	5	2	14	56	77
1999	35	5	1	8	62	76
Mean	34.8	4.6	2.4	11.8	62.4	81.2

Source: TØI report 747/2004

The mean annual number of pile up injury accidents assumed to be affected by Traffic Warning Systems is 35. A total of slightly more than 80 people are killed or injured in these accidents each year.

The size of the effect of Traffic Warning Systems on these accidents is hard to determine. By analogy to category D, disabled vehicles, a 40% effectiveness in preventing the accidents will be assumed.

It will be assumed that Traffic Warning Systems has the potential to prevent 40% of all pile up injury accidents that occur in restricted sight conditions, except rear end accidents.

4.3 Possible Variation in the Effects of Traffic Warning Systems according to Accident Severity

When a driver is warned of a traffic hazard, two reactions are likely to occur. First, the driver becomes more attentive, and starts looking for the hazard, if it is not already within the field of view. Second, once the hazard is seen, the driver slows down, or otherwise prepares for stopping or making an evasive manoeuvre.

These reactions are likely to have two effects. The first effect is that some accidents are avoided altogether. The second effect is that many of the accidents that continue to happen, perhaps because the driver reacted too late to the warning, will happen at a lower speed. This means that the accidents will be less severe.

These effects can be modelled by assuming that the effects of Traffic Warning Systems vary according to accident severity, or more precisely injury severity. If, for example, Traffic Warning Systems is assumed to reduce all injury accidents of a certain type by 40%, one could assume that fatal accidents are reduced by, say, 50%, and accidents in which there are only slight injuries reduced by slightly less than 40%. The mean accident reduction for all levels of injury severity would be 40%.

Is it reasonable to assume such a gradient in the effects of Traffic Warning Systems with respect to accident severity? For most of the target accidents, such an assumption appears to be reasonable. The only exception is accidents at railway crossings. It is unlikely that Traffic Warning Systems can reduce the severity of these accidents. The driver either detects the train in time, in which case the accident is avoided, or he does not, in which case the accident occurs with the same severity as it would if Traffic Warning Systems did not exist.

Table 8 summarises the assumptions that have been made with respect to the effects of Traffic Warning Systems in preventing injuries at different levels of severity.

Table 8: Summary of the assumed potential effects of Traffic Warning Systems. Percent reduction of the number of injured road users in target groups of accidents.

	Percent reduction of the number of			
Category of accidents	**Killed**	**Very seriously injured**	**Seriously or slightly injured**	**Mean for all injuries**
A. Emergency vehicle	60	50	38	40
B: Road works	40	30	18	20
C: Railway grade crossings	50	50	50	50
D: Disabled vehicle	60	50	38	40
E: Pile up accidents	60	50	38	40

Source: TØI report 747/2004

4.4 Number of injured Road Users prevented by a Universal Application of Traffic Warning Systems

Based on the assumptions made in chapter 3, and in sections 4.2 and 4.3, the annual number of injured road users that can be prevented by a universal application of Traffic Warning Systems can be estimated. Table 9 summarises the results of the estimation. The number of target accidents affected by Traffic Warning Systems, as given in Tables 2 and 8 can be summarised as follows:

- 115 injury accidents per year, in which there are
- 10 road users killed
- 5 road users very seriously injured
- 23 road users seriously injured, and
- 175 road users slightly injured, for a total of
- 213 road users killed or injured.

Note that the numbers given for all target accidents may differ slightly from the sum of the numbers given for each category of targets accidents, due to rounding errors.

Table 9: Annual number of injured road users that can be prevented by a universal application of Traffic Warning Systems.

	Annual number of injured road users prevented			
Category of accidents	**Killed**	**Very seriously injured**	**Seriously or slightly injured**	**Total**
A. Emergency vehicle	0.4	0.2	8.1	8.7
B: Road works	1.0	0.5	9.2	10.7
C: Railway grade crossings	0.7	0.0	5.0	5.7
D: Disabled vehicle	0.6	0.2	17.7	18.5
E: Pile up accidents	2.8	1.2	28.4	32.4
All target accidents	5.4	2.1	68.5	76.0

Source: TØI report 747/2004

It has been assumed that all cars (and tractors used in agriculture) are equipped with Traffic Warning Systems. It has been estimated that a total of 76 cases of personal injury can be prevented each year. About 5 of these are fatal injuries, 2 are very serious injuries, and 68 are serious or slight injuries (8 serious, 60 slight).

These estimates are obviously highly uncertain. There are many sources of uncertainty, but not all of them will be discussed here. Only one source of uncertainty has been estimated. That is the contribution that random variation in the number of injured road users makes to the uncertainty in the estimated number of injured road users prevented. The contribution from random fluctuations of the number of injured road users was estimated by relying on the Poisson probability law. This probability law describes random variation in the number of accidents. Strictly speaking, it does not apply to accident victims, but was nevertheless used as an approximation. Table 10 presents the results of the estimates. The estimates employed the total number of injured road users for five years (1995-1999), in order to make the best use of the data that have been collected.

Table 10: Uncertainty in the estimated effects of Traffic Warning Systems on the number of injured road users prevented

	Change in the annual number of injured road users. Negative numbers denote increases		
Injury severity	**Best estimate**	**Lower 95% limit**	**Upper 95% limit**
Fatal injuries	5.4	3.3	8.6
Very serious injuries	2.1	1.1	4.5
Serious and slight injuries	68.5	60.5	77.4
All levels of severity	76.0	64.9	90.5

Source: TØI report 747/2004

The best estimate is a reduction of the annual number of injured road users of 76. The lower limit is 65, the upper limit is 91. In relative terms, the greatest uncertainty attaches to estimates of the effects on the number of killed or very seriously injured road users.

4.5 Potential Effects on Property-Damage-Only Accidents

The association of motor vehicle insurers in Norway keep an accident statistics, called TRAST. This accident record is based on claims filed by policy holders, and contains few details describing each accident. It has not been possible to list the relevant categories of accidents from the TRAST system. In order to estimate the potential impacts of Traffic Warning Systems on property-damage-only accidents, it has therefore been necessary to rely on other sources of data.

In the surveys that were made some years ago regarding accident rates for emergency vehicles (Frøyland 1983, Fosser 1986), information was collected on the number of property-damage-only accidents involving emergency vehicles on duty. The surveys found that:

- For ambulances, there are about 4 property-damage-only accidents for each injury accident.
- For fire engines, there are about 12 property-damage-only accidents for each injury accident.
- For police cars, there are about 20 property-damage-only accidents for each injury accident.

As far as road works accidents are concerned, no statistics concerning the number of property-damage-only accidents has been found. As an approximation, it is assumed that the number of property-damage-only accidents for each injury accident equals the average ratio for rural areas in Norway, which is about 6 (Elvik and Muskaug 1994).

For railway crossing accidents the number of property-damage-only accidents is likely to be very low, as the severity of these accidents is rather high. As an approximation, the difference between the number of accidents recorded by the rail track administration, and the number of accidents in the official statistics for injury accidents, is used. Based on Table 4, this difference is 6 accidents per year, corresponding to a frequency of a little more than 1 property-damage-only accident for each injury accident.

For accidents involving disabled vehicles, a previous estimate of the number of rear end collisions outside built up areas is used (Elvik and Muskaug 1994). This estimate indicates that there are slightly more than 2 rear end collisions with property damage only for each rear end collision resulting in personal injury, outside built up areas.

Finally for pile up accidents, it is assumed that the number of such accidents resulting in property-damage-only is about 20 for each pile up accident resulting in injury. This corresponds to the average ratio of PDO-accidents to injury accidents in built-up areas (Elvik and Muskaug 1994).

The effects of Traffic Warning Systems with respect to property-damage-only accidents are difficult to predict. It has been assumed that, for most of the target categories of accidents, effects are smaller for slight injuries than for fatal or very serious injuries. It has therefore been assumed that the effects of Traffic Warning Systems in preventing property-damage-only accidents is about 2/3 of the effects assumed for accidents resulting in slight injuries. The only exception is railway crossing accidents, for which the effect is not assumed to vary according to accident severity. This means that Traffic Warning Systems have been assumed to:

- Reduce emergency vehicle accidents resulting in property damage only by 25%,
- Reduce road works accidents resulting in property damage only by 12%,
- Reduce railway crossing accidents resulting in property damage only by 50%,
- Reduce disabled vehicle accidents resulting in property damage only by 25%, and
- Reduce pile-up accidents resulting in property damage only by 25%.

Based on these assumptions, it has been estimated that Traffic Warning Systems may prevent around 266 property-damage-only accidents per year in addition to the injury accidents that are prevented.

A simple way to estimate the uncertainty of this estimated effect is to take 1.96 times the square root of the number. The lower 95% confidence limit then comes to 234 prevented accidents, the upper 95% confidence limit comes to 300 prevented accidents.

4.6 Potential Effects of Traffic Warning Systems on Traffic Operations

In addition to preventing accidents by warning of traffic hazards, Traffic Warning Systems may affect traffic operations favourably in other ways. More specifically, the following potential impacts of the system can be envisaged:

- Today, emergency vehicles on duty are sometimes obstructed by other motor vehicles. When an approaching emergency vehicle transmits a warning signal, the chances may increase that other road users move to the side to give free access to the emergency vehicle. It is, however, not possible to quantify this impact.
- Disabled vehicles will warn approaching motorists in both directions. Today, the warning triangle which is supposed to be used warns only those approaching the disabled vehicle from one direction. Again, quantifying possible benefits of this impact is not possible.
- Vehicles which leave the roadway may be located earlier than they might otherwise have been. This will not prevent any accidents, but may lead to a more rapid deployment of rescue services, which may in turn reduce the consequences of any personal injuries sustained. Quantifying the benefits of this impact is not possible at the current state of knowledge.

4.7 Potential Impacts of Traffic Warning Systems in other Countries

Norway is a sparsely populated country, in which most roads carry rather small traffic volumes. Dense traffic by international standards, like say on urban arterial roads with an average daily traffic of more than 50,000 vehicles, is hardly found. Motorways extend to only 150 km of road, as opposed to several thousands of kilometres in the large European countries (France, Germany, Great Britain, Italy). Massive pile up accidents occur much more frequently on motorways in the large European countries than in Norway.

Although it is impossible to estimate the effects on accidents of Traffic Warning Systems in other countries, without collecting data similar to those used in this report, it is reasonable to expect the effects to be greater than in Norway.

5 Potentially Adverse Effects of Traffic Warning Systems

Changes in road user behaviour in adaptation to technical safety measures is a pervasive phenomenon. It has been shown, for example, that when road lighting is installed, drivers tend to go faster and slightly reduce their levels of attention (Assum et al 1999). Studded tires induce faster driving, and a less adequate adaptation to changes in the road surface conditions (Elvik 1999, Fridstrøm 2000). Quite often, the behavioural changes that take place tend to reduce the safety effects of the measure, that is its effect on accidents are smaller than they might have been if road user behaviour had remained unchanged.

There are many ways in which road users can change their behaviour, and not all of them are amenable to very reliable measurement. Changes in driving speed can be measured with reasonable accuracy, but changes in the level of attention paid to traffic are very much harder to detect and measure reliably. Hypotheses concerning road user adaptation to technical safety measures cannot therefore always be tested as rigorously as researchers would ideally like. Despite this, it is useful to discuss in qualitative terms the possibilities of behavioural adaptation to a new technical safety device. Is it conceivable that the application of Traffic Warning Systems could lead to changes in road user behaviour that might offset the intended safety benefits of the system? This chapter will discuss this question, and point to some possible adverse impacts of Traffic Warning Systems. It must be stated right at the outset, however, that it is impossible to draw a definite conclusion.

5.1 Road User Response to Warnings that induce unresolved Uncertainty

Imagine the following scenario: a driver is driving in city traffic with a dense street network in a grid layout. The red warning signal starts flashing in his car. What does this mean? There are at least two possibilities: either an accident has occurred somewhere within a radius of, say, 500 metres, or a disabled vehicle has activated the warning system somewhere in the same area. It could even be the case that both events have occurred. Unless the driver happens to drive past the location at which the warning signal was activated, he will never know why the signal went on. In city traffic, there is a non-negligible chance that the driver will never pass an accident site or the site where a disabled vehicle has stopped. After a while, the warning signal may cease flashing, without the driver ever knowing why it came on.

A situation like this creates an uncertainty which is never resolved. Most people are averse to diffuse information, that is information that can be interpreted in many ways, and which requires additional information in order to be interpreted correctly. The problem with Traffic Warning Systems in city traffic, is that there is no guarantee that the driver will get the additional information needed to know exactly why the warning signal came on.

If this happens often, some drivers may start to ignore the warnings in city traffic, thinking perhaps that these warnings do not concern them, since they never pass the site where the warning signal was activated. Such thinking is obviously dangerous. The fact that a driver may feel that the warning signal did not concern him on a particular occasion, does not mean that it will never concern him. On the contrary, barring technical malfunctioning, every warning signal will be real, and will be activated only when there is a real traffic hazard in the area.

Could situations like these lead drivers to ignore the warnings given by Traffic Warning Systems? Perhaps it could, and perhaps not. One could argue that drivers do not need to know exactly why a warning signal comes on. All they need to know, is that as long as the warning signal is on, they should be particularly attentive and prepared to react quickly. If this is the way drivers react, no harm is done by issuing a warning, the exact reason for which the driver may never find out. If, on the other hand, drivers are irritated by not finding out exactly why the warning signal came on, the distraction induced by this irritation could be detrimental to road safety.

5.2 The Problem of frequent Alarms being ignored

If warnings are given very often, drivers may come to regard them as “false alarms” and ignore them. The words “false alarms” have been put in quotation marks, since it is assumed that the system will not be activated unless there is a specific reason for doing so, related to the situations and types of accidents that have been discussed in previous chapters.

The problem is whether these situations occur so frequently, that drivers on a normal trip will be warned several times. The first type of traffic hazard covered by Traffic Warning Systems is emergency vehicles on duty. How often does a driver encounter this situation? According to surveys made at the Institute of Transport Economics (Frøyland 1983, Fosser 1986), the annual number of vehicle kilometres driven by emergency vehicles on duty can be estimated to:

- About 2,700,000 kilometres by ambulances (around 1980)
- About 130,000 kilometres by fire engines (around 1980)
- About 1,900,000 kilometres by police cars (around 1980)

In sum, this is about 4.7 million vehicle kilometres of driving. This constitutes about 0.017 percent of all driving in Norway at the time. This means that the chances of a driver being warned of an emergency vehicle on a given trip is almost zero. These warnings will not be given very frequently.

The second type of hazard covered by Traffic Warning Systems are road works sites. Unfortunately, no statistics has been found showing the number of such sites. The number will, however, be small compared to the length of the road network. It is therefore reasonable to conclude that warnings of road works are unlikely to be given so often as to be interpreted as false alarms.

There are about 4,000 unprotected railway-highway grade crossings in Norway. Most of these are used by just a few vehicles. The number of trains is also likely to be rather low, normally less than one per hour at the railway lines where most of the unprotected crossings are located. Frequent warnings of approaching trains are therefore unlikely to occur.

As far as disabled vehicles are concerned, statistics for road tunnels suggest that there are about 40-80 incidents involving disabled vehicles for each police reported injury accident (Elvik, Mysen and Vaa 1997). If 60 incidents per injury accident is taken as the best estimate, and the mean injury accident rate is set to 0.25 accidents per million vehicle kilometres, the rate of incidents involving disabled vehicles comes to about 15 per million vehicle kilometres of travel. For a car driver who drives about 14,000 kilometres per year (which is the current average), this means that a disabled vehicle is encountered on the average once every 4-5 years. Casual observation suggests that this is an underestimate, but even if the true frequency was, say, ten times higher than assumed in the estimate, an average driver would still encounter a disabled vehicle only about twice per year. The problem of alarms going off too frequently can therefore be ruled out.

Accidents occur even more rarely than events involving disabled vehicles. For most drivers, several years pass between each time they are witnesses to an injury accident or pass by an injury accident site. Even property-damage-only accidents are seen only a very few times each year, or perhaps not at all. Hence, warnings of pile up accidents are, like the other warnings likely to be activated very rarely.

In summary, the likely frequency of warnings activated by Traffic Warning Systems is very low, certainly far less than once per trip, probably less than one per month, but perhaps more often than one per year. In view of this, it seems very improbable that these warnings are going to be disregarded by drivers because they come on too often.

5.3 Problems related to Apparent Unreliability of the System

In the estimates made of the potential impacts on accidents of Traffic Warning Systems, it has been assumed that all motor vehicles have the system. This is an essential assumption. If only a few motor vehicles have the system, problems may arise because of the apparent unreliability of the system. Warnings are activated by vehicles that have the system, but not by vehicles that do not have it. In such a situation, it is impossible for the driver to rely on the system. The types of traffic hazards covered by the system may arise even if no warning is activated. The utility of the system is then likely to be greatly reduced.

5.4 Problems related to excessive Reliance on the System

The converse of the problem mentioned above may occur in the situation in which nearly all motor vehicles have the system, but some very few remain that do not have it. In such a situation, drivers may tend to assume that *all* motor vehicles have the system. By relying exclusively on the warnings activated by Traffic Warning Systems, drivers may be at an increased risk of overlooking these hazards in the few cases when no warning of them is given. This might in turn increase the risk of accidents when the hazards covered by Traffic Warning Systems are encountered without a prior warning of them.

5.5 Conclusions with respect to Behavioural Adaptation

Four possible mechanisms of unintended behavioural adaptation to Traffic Warning Systems have been briefly discussed in this chapter:

- The possibility that the warnings are ignored if, on repeated occasions, the driver gets a warning, but does not find out why the warning was given, because he or she does not drive past the site where the warning system was activated.
- The possibility that the warnings are ignored, because the warning is activated very often, in most cases for reasons that are not apparent to the driver.
- The possibility that the warnings are ignored, because of the apparent unreliability of the system in a situation when only a few vehicles are equipped with it.
- The possibility of excessive reliance on the system, in a situation when nearly all vehicles have the system, but a few remain that do not have it. These few vehicles may then represent an added element of risk.

The third and fourth of these possibilities can, at least to a large extent, be prevented by requiring by law all motor vehicles to have the system. In the estimates that have been made of the effects on accidents of Traffic Warning Systems, it has been assumed that all cars and tractors have the system. Although a compliance rate of literally one hundred percent is difficult to attain in practice, one can come very close to it. The compliance rate for the coloured stickers Norwegian car owners are required to put on their vehicle license plates each year is close to one hundred percent. A law will, however, most likely apply to new vehicles only. Full penetration of the system may then take up to 15-20 years.

The types of traffic hazards that will be covered by Traffic Warning Systems do not occur very frequently. In view of their likely frequency of occurrence, one may almost rule out the possibility that the warning system will be activated almost constantly. It is, indeed, not likely to be activated at all during most trips. For most drivers, the warning system will probably not be activated more often than once per month, on the average. However, drivers should be alerted to the very likely possibility that the frequency of warnings will vary substantially from one month to the next. There may, for example, be three warnings in one month, followed by several months without any warnings, and then one month with one warning, and so on. The basically random nature of the occurrence of the traffic hazards that are covered by the system makes it inevitable that the number of warnings per unit of time will vary a lot from one period to another.

Will drivers pay attention to the warnings even if they do not immediately see the hazard that has activated the warning? Given the fact that warnings will probably be given fairly rarely, drivers are likely to pay attention to them. Many warnings and messages given to drivers by means of radio are of a rather non-specific nature, but are nevertheless taken seriously by most drivers. After a cold night in the autumn, for example, a radio station may tell listeners: “Take care. The roads are very slippery today, after the cold night.” Many drivers will pay attention to this message, even if not all roads are equally slippery, and some cars have better tires than others.

It is concluded that the possibility cannot be ruled that unintended behavioural adaptation may take place when Traffic Warning Systems are introduced. It is impossible to quantify the nature and extent of any behavioural adaptation in advance. On the basis of the discussion in this chapter, however, it seems improbable that any behavioural adaptation, were it to occur, would completely offset the intended effects of Traffic Warning Systems on traffic safety.

6 Cost-Benefit Analysis

6.1 The Benefits to Society of preventing Road Accidents

Road accidents impose great costs on society, in terms of, for example, medical treatment, repair or replacement of damaged motor vehicles and loss of quality of life in a wide sense. Preventing road accidents saves this cost. Table 11 presents the most updated estimates of road accident costs for Norway.

Table 11: Costs of road accident injuries in Norway. 1999-prices. Updated estimates used by the Public Roads Administration (Vegdirektoratet, unpublished)

Injury severity	Cost per case NOK 1999 prices
One fatal injury	20,150,000
One very serious injury	13,800,000
One serious injury	4,590,000
One slight injury	600,000
Property damage only	18,000
One average injury accident	2,400,000
One average property damage only accident	36,000

Source: TØI report 747/2004

It is important to stress the fact that a large part of the benefits to society of preventing road accidents relates to the valuation of quality of life, a non-market good. Only a minor proportion of the savings are actually savings in out-of-pocket expenses for the individual car owner. In Table 12, an attempt has been made, on the basis of Elvik (1994) to allocate the savings gained in preventing accidents to different sectors of society.

Table 12: The nature of the savings in costs gained by preventing road accidents

	Percent allocation of the benefits (cost savings) of preventing road accidents				
		Savings in out-of-pocket expenses to			
Injury severity	Gain in welfare (non-market)	Car owners and their family	Private third parties	The public sector	Total
Fatality	79	12	0	9	100
Very serious injury	51	16	3	30	100
Serious injury	49	11	7	33	100
Slight injury	59	24	7	10	100
Property damage only	0	100	0	0	100

Source: TØI report 747/2004

The benefits to society of preventing road accidents comprise all cost elements, irrespective of whether or not these costs manifest themselves in market transactions or represent a valuation of welfare aspects not subject to trade. In principle, it is possible for a technical system, like Traffic Warning Systems, to give a societal benefit which is greater than the costs, while it is at the same time difficult to make a profit by marketing the system. This report does *not* contain an analysis of the market prospects of the system, only its benefits and costs from a socio-economic point of view.

6.2 Benefits and Costs of Traffic Warning Systems from a Societal Point of View

According to the best estimate, rounded to the nearest integer, a universal application of Traffic Warning Systems has the potential to prevent:

- 5 fatal injuries per year
- 2 very serious injuries per year
- 8 serious injuries per year
- 60 slight injuries per year
- 266 property-damage-only accidents per year.

Take care to note that the numbers of prevented injuries refer to the number of *injured persons*, whereas the number of prevented property-damage-only accidents refers to *accidents*.

Assuming that Traffic Warning Systems will be required for all motor vehicles, the system needs to be installed in 2,720,605 motor vehicles (as of December 31, 1999). When mopeds, snow scooters and motorcycles are omitted, the number of vehicles needing the system comes to 2,480,956. In the calculation below, 2.5 million vehicles has been assumed, since the number of motor vehicles continues to grow from year to year.

Based on the reports by Pleym (2000A, 2000B), the cost of the radio unit is assumed to be 200 NOK per vehicle. It is assumed that each car owner can install the unit by means of an adhesive tape. No connections to the rest of the electrical system in the car is needed. Electricity will be supplied by means of battery that starts making a “squeaking” noise when it is about to expire. Car owners will then have to change the battery. It will be assumed that the battery needs to be changed once per year. Installing the system for the first time is assumed to cost 25 NOK. Total costs of installing the system the first time become:

2,500,000 · 225 = 562.5 million NOK

A new battery is assumed to cost NOK 25. The present value of the costs of annual changes of battery, for an average period of seven years, using an 8 percent annual discount rate, then become:

2,500,000 · 25 · 5.206 = 325.5 million NOK

The present value of total costs is 888 million NOK.

As for the benefits, a time horizon of 7 years has been assumed. This assumption is based on the fact that the mean age for a car in Norway is 10 years, and that the mean age of a car at scrapping is 17 years. Thus, the average remaining time of use of a car in Norway is 7 years. Since this must be regarded as a high risk investment, a discount rate of 8 percent per year has been used (Finansdepartementet 2000).

Applying these assumptions, the present value of the benefits come to about 1,150 million NOK. About 560 million NOK of these savings refer to the prevention of fatal injuries. 50 million refer to the prevention of property-damage-only accidents. The benefits are clearly greater than the costs of installing and maintaining the system. The benefit-cost ratio is 1,150/888 = 1.3.

If a discount rate of 4 percent per year is applied, the lowest rate recommended for investment assessment in the public sector, the present value of benefits becomes 1,327 million NOK, which is considerably more than the costs of the system. A possible problem of relying on a battery to supply power to the system, is that some owners of motor vehicles will fail to change the battery when that is necessary. This will in turn reduce the benefits of the system.

To test how sensitive the results are with respect to a lack of compliance, suppose that only 50% of the batteries are changed when they ought to be. This reduces the present value of the annual cost of the system from 325 to 163 million NOK. Total costs, assuming that everybody installs the system in the first place, are reduced from 888 to 725 million NOK. If benefits are also reduced by 50%, the best estimate of benefits becomes 576 million NOK, which is smaller than the costs. This shows that a high rate of compliance with the system is needed in order to maintain benefits and obtain a favourable benefit-cost ratio.

In practice, benefits are not likely to be reduced by as much as 50%, even if 50% of vehicle owners fail to change batteries on time. Failure to change batteries is most likely to occur among those who own old vehicles, which are approaching their scrapping age. These vehicles tend to be driven less than newer vehicles, and are involved in fewer accidents (Fosser and Christensen 1998).

In order to ensure a high level of compliance with the system, it is probably necessary to make it mandatory by law. The police will then have the opportunity of reacting against those who do not have a functioning system installed in their vehicle.

7 Discussion and Conclusions

Assessing the potential impacts of new technology on road accidents is not an exact science. There are many choices to be made, and all of them affect the results of the assessment. The first choice that was made in this analysis, was the *definition of the target groups of accidents*, that is those accidents that can be assumed to be affected by Traffic Warning Systems. Based on the description of the system, five categories of target accidents were identified:

- Accidents involving emergency vehicles on duty (that is employing flashing lights and sound signals)
- Accidents at road works sites, involving stationary or slow moving machines or equipment used in road works
- Accidents at unprotected at-grade crossings between railways and highways
- Accidents in which disabled vehicles (i. e. vehicles with engine trouble, flat tires, or other mechanical problems) are struck by other vehicles
- Pile up accidents, that is accidents in which more than two vehicles are involved, and in which the first two vehicles are able to warn other vehicles of the accident in time for them to avoid becoming involved in it.

The annual number of accidents in these categories was determined on the basis of the official statistics for personal injury accidents in Norway. The mean annual number of accidents in 1995-1999 was 115, with 213 people injured each year.

Were these categories of target accidents too generously or too narrowly defined? With respect to the first category of accidents, it was decided to include only accidents involving emergency vehicles on duty. Emergency vehicles do become involved in accidents even off duty. When emergency vehicles are off duty, however, they do not have greater need for speedy travel than other motor vehicles. It has therefore been assumed that the warning system will be activated only when emergency vehicles are on duty.

As far as accidents at road works sites are concerned, the exact number could not be found in accident statistics, and an approximate definition had to be adopted. This approximate definition is probably generous and overstates the actual number of injury accidents at road works sites.

All accidents at railway crossings were included, which is also a generous definition, since Traffic Warning Systems are ideally speaking supposed to be used only at unprotected crossings. It was judged, however, that trains would run with the system on at all times, rather than switching it on and off every time an unprotected crossing is approached. There are, on the average, about one unprotected crossing per kilometre of railway, meaning that the system would have to be switched on and off very often, if it was supposed to be used only in the vicinity of unprotected crossings.

The number of accidents involving disabled vehicles cannot be identified very precisely in official road accident statistics. The approximation used is generous, since it includes all parked vehicles that are struck outside built-up areas. Not all of these parked vehicles will be disabled; hence, not all of them will switch on the warning system. It is therefore highly likely that the true number of accidents involving disabled vehicles is lower than the approximate number used in this report.

The most difficult category of accidents to define, was pile up accidents. The total number of such accidents can be found in official road accident statistics. The difficulty is knowing how quickly these pile ups happen. If the vehicles pile up very quickly, no warning could have any effect, simply because there would not be enough time to react. Based on general knowledge of the dynamics of pile up crashes, in particular rear end collisions, it was concluded that the majority of these accidents probably happen too quickly for a warning system to be effective. It was judged that the only group of pile up accidents for which it was reasonable to assume a time lag with respect to the arrival of successive vehicles becoming involved in the accident, was pile up accidents that occur in restricted sight conditions. This assumption is of course debatable, but it was felt to be better to adopt a narrow definition of the accidents that can be affected than to adopt an obviously too generous definition.

Table 13 summarises the main points of this discussion.

Table 13: Accuracy of the definition of the target groups of accidents assumed to be affected by Traffic Warning Systems (TWS)

Category of accidents	**Definition of accidents affected by TWS**
A: Emergency vehicles on duty	As accurate as available information permits
B. Road works sites	Probably too generous
C: Railway crossings	Slightly too generous
D: Disabled vehicles	Probably too generous
E: Pile up accidents	Difficult to assess; may be too restrictive

Source: TØI report 747/2004

When all target accidents are seen as a whole, it cannot be claimed that the definitions chosen are either too generous or too restrictive. For some categories, the definition is likely to be too generous. For pile up accidents, it may be too restrictive.

There is, however, at the current state of knowledge, no way of knowing for sure whether the definitions of targets accidents chosen in this report are too generous or too restrictive. It is only when Traffic Warning Systems are implemented in real traffic on a grand scale that it will become possible to assess more definitely which categories of accidents are affected by the system.

The second important decision made in this report, was the choice of assumptions concerning *the effects of Traffic Warning Systems in preventing target accidents*. A fully satisfactory basis for this choice could not be found, and reliance had to be placed on reasoning by analogy, based on similar systems or the results of in-depth accident investigations. On the average, Traffic Warning Systems has been assumed to reduce the number of fatal injuries by slightly more than 50%, the number of very serious injuries by about 40%, and the number of serious or slight injuries by about 35%. The target number of property-damage-only accidents has been assumed to be reduced by about 25%.

These effects are comparatively large, compared to the effects attributed to many other road safety measures. Very few measures have been found to reduce the number of fatal injuries in the target group by more than 50%; not even seat belts are that effective (Elvik, Mysen and Vaa 1997).

It would definitely be too optimistic to assume that Traffic Warning Systems could eliminate the accidents in the groups affected. No technical safety system is one hundred percent effective. There will always be some drivers who fail to detect a warning, or choose to ignore it. There will always be some drivers who choose an inappropriate emergency reaction, which does not succeed in preventing the accident. There will always be the occasional – hopefully very rare – malfunctioning of the system. For these, and a number of other reasons, one cannot assume that a warning system can ever prevent all the accidents involving the types of traffic hazards that activate the warnings.

The estimated number of injuries or accidents that can be prevented is of course highly uncertain. No attempt was made to estimate all sources of uncertainty. The uncertainty that was estimated, comprises just the contribution of random variation of the number of accidents or injured road users. The true uncertainty may be substantially greater than estimated in this report.

A simple cost-benefit analysis was made. In this analysis, official estimates of road accident costs were applied. By international standards, the official valuation of road safety is high in Norway. Very few other countries value the benefits of preventing a road accident fatality more highly in monetary terms than the Norwegian government does. Although higher estimates can be found in the research literature dealing with the monetary valuation of road safety, some of the highest estimates come from studies that are suspect, due to methodological flaws. The accident costs that were used are very close to the results of the most recent, and most methodologically rigorous, studies that have been made in this area. It is difficult to make a case for applying substantially higher costs than those that were used.

The main conclusions of this report are therefore likely to be quite robust. These conclusions can be summarised as follows:

1. Traffic Warning Systems is a radio based system, designed to warn drivers of specific traffic hazards within a range of approximately 500 metres. Warnings will be displayed as a flashing signal on the dashboard of the car. The system, as currently developed, is intended to comprise the following types of hazards: (a) Emergency vehicles on duty, (b) Stationary or slow moving road works, (c) Trains approaching unprotected railway grade crossings, (d) Disabled vehicles left on the road shoulder, and (e) Accidents in restricted sight conditions in which many cars are piled up.
2. Official statistics for injury accidents has been applied to estimate the number of accidents that can be affected by a system that warns of the traffic hazards

listed above. During the period 1995-1999, there were, on the average, about 115 injury accidents with 213 injured road users each year.

3. It was estimated that a universal application of Traffic Warning Systems on all motor vehicles in Norway can prevent, rounded to the nearest whole number, 5 fatalities per year, 2 very serious injuries, 8 serious injuries, and 60 slight injuries. In addition, about 266 accidents with property damage only can be prevented each year.
4. The number of accidents or injuries that can be prevented is uncertain. The range of possible outcomes attributable to random variation alone is 3 to 9 prevented fatalities per year, 1 to 4 prevented very serious injuries, 6 to 10 prevented serious injuries, and 54 to 67 prevented slight injuries. For property damage only accidents, the range is from 234 to 300 prevented accidents.
5. The possibility that unintended behavioural adaptation to the system may greatly reduce these safety benefits was discussed. Although a definite conclusion cannot be drawn, it appears to be rather improbable that the system would lead to behavioural adaptation to such an extent as to eliminate the intended safety benefits.
6. Each radio unit was assumed to cost about 200 NOK. Installing it was assumed to cost about 25 NOK, for a total cost of 225 NOK per motor vehicle. The total costs of equipping all motor vehicles in Norway with the system then come to 562.5 million NOK. Mopeds, snow scooters and motorcycles were assumed not to be equipped with the system.
7. The system relies on a battery to supply electricity. It was assumed that the battery needs to be changed once per year, at an annual cost of 25 NOK per motor vehicle. For the current vehicle fleet, the present value of the annual cost of changing batteries comes to 325.5 million NOK. Total costs of the system, assuming perfect compliance, thus become 562.5 + 325.5 = 888 million NOK.
8. Benefits of the system were assessed in monetary terms by applying current official road accident costs for Norway. Since the system will be retrofitted into the existing vehicle fleet, a time horizon of 7 years was applied. A discount rate of 8% per year was used. The present value of the benefits of the system then come to about 1,150 million NOK. Benefits are greater than costs by a wide margin. The benefit-cost ratio is about 1.3.
9. There is a risk of declining compliance with the system over time, as some vehicle owners fail to change batteries on time. This could lead to an erosion of the benefits of the system. It is, however, rather unlikely that this erosion would be so severe as to make benefits smaller than costs, although such a possibility cannot be entirely ruled out.
10. In order to ensure a high level of compliance with the system, it would have to be made mandatory by law. The police would then have the authority to react against those who do not install the system or keep it in working order.

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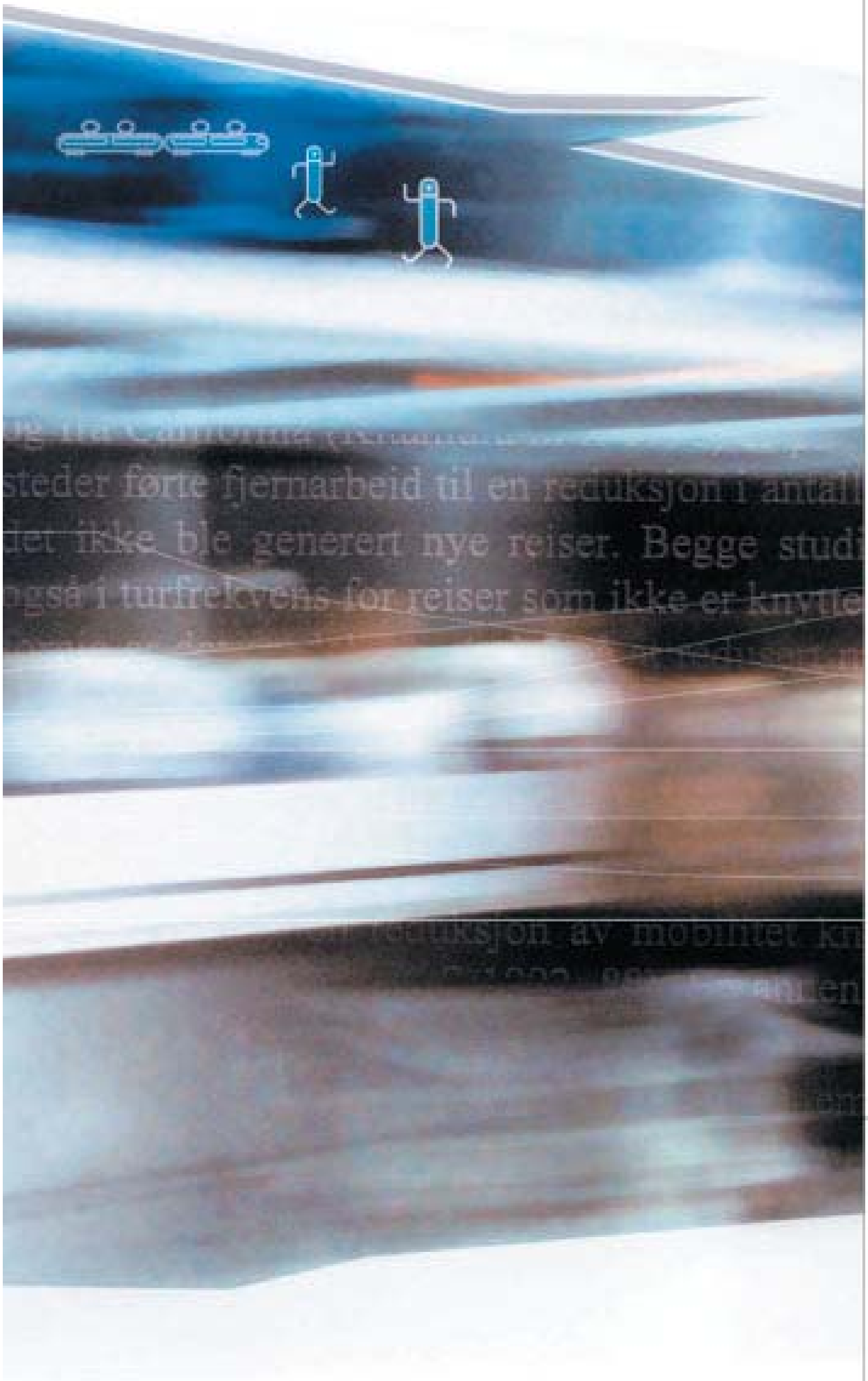

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