Driver Support Systems and Road Safety Outcomes:

Potential Effects on Fatal Accidents

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ABSTRACT

A prime objective of Intelligent Transport Systems (ITS) which are applied in road transportation is to reduce the number of accidents. A subset of ITS is Driver Support Systems (DSS), i.e. systems that support the driver in handling information, provide warnings, or interfere in the process of maneuvering the car. The present overview will provide ex ante estimates regarding the effects on accidents of Intelligent Speed Adaptation, Maximum Speed Governor, Alcolock, Seat-belt Lock, Sleep Warning Systems, Programmable Ignition Key, Adapative Cruise Control and Electronic Stability Control. The estimation methods will, except for ESC, be by proxy, i.e. assumed effect on certain accident types or other surrogate variables. Focus will be on systems that limit or hinder drivers in engaging in behaviours that are deliberate violations of traffic law. Estimates of lives saved are based on in-depth investigation of fatal accidents possibly prevented if respective systems had been installed in the cars when the accidents took place.

Keywords: Driver support systems, road safety, behaviour, accidents, estimated effects [1]

1. INTRODUCTION

One of the prime objectives of developing intelligent transport systems (ITS) to be applied in road traffic is to reduce the number of accidents. Despite more than 20 years of development

[1] Paper presented at 20th World Congress on ITS, Tokyo 16th October 2013

there are still only a handful of systems that have matured into widespread deployment in road traffic to a level where the effects on accidents have been accomplished. Antilocking Brake Systems (ABS), Electronic Stability Control (ESC), speed cameras and Variable Message Signs (VMS) belong to this group of systems [1] [2] [3].

The European car industry established the PROMETHEUS-program in 1986. The main objective was then to intensify research on high-technological systems that could promote car safety, mobility and face competition from America and Japanese car industries. The EU regarded this as a significant challenge for their R&D-activities and in 1988 they launched the research program DRIVE where the EU invited European research institutions for cooperation in order to solve research tasks which the EU defined as important for supporting the European car industry. High-technological systems which have been developed and applied within the road traffic system have had different terms since the start in the late 1980's, including Road Transport Informatics (RTI), Advanced Telematics in Transport (ATT), Intelligent Vehicle-Highway Systems (IVHS), In-Vehicle-Information-Systems (IVIS), and Advanced Driver Assistance Systems (ADAS), before agreeing on the generic term Intelligent Transport Systems (ITS) in 1996. However, concepts may be too generic and we prefer to label the systems addressed in the present context as *Driver Support Systems (DSS),* because that is what the systems consider actually do: They support drivers' information processing and decision-making. Another benefit by using this label is the avoidance of any discussion about systems' inherent *intelligence,* i.e. there would no longer be a need to consider why and how the asserted intelligence of systems may express itself. What is retained is what is considered to be the essence regarding safety outcomes: How systems affect driver behaviour and accidents in road traffic.

2. ITS AND EFFECTS ON BEHAVIOUR AND ACCIDENTS

The first evaluation study we know of regarding what was then labeled "selected Prometheus functions" was done by BASt as part of the PROMETHEUS-project [4]. What is particularly interesting in this 24-year old study is their use of how hypothetical systems might act on accident types by considering accident types in official accident statistics, as for example accidents associated with lane changing, following too closely, overtaking, etc, and just ask whether a hypothetical system could have prevented a given accident type. A state-of-the-art study in 2007, i.e. 18 years later, identifies 33 ITS-systems, where 13 systems have been studied according to their effects on accidents in real traffic, while the outcomes of the rest of the systems – i.e. 20 systems – were evaluated by proxy methods analogues to the one used by Marburger et al in 1989. The fact that proxy evaluations methods is still needed by 2007, illustrates two main issues: Firstly, that the technological development of ITS is slow, secondly, car manufacturers and road authorities have been reluctant and apprehensive about a large-scale introduction of systems in real traffic. However, some progress has been made:

Almost all of the 20 systems where effects on accidents are missing, have been evaluated in terms of their outcomes on behaviour [1].

One of the big issues when considering ITS and road safety is naturally how drivers will adapt to new systems in terms of increasing driving speeds and lowering attention when driving, a phenomenon often referred to as *risk compensation*. We know from research on the outcomes of ABS that this system changes driver behaviour by making drivers drive faster and more aggressively [5]. Regarding effects of ABS on accidents we also know that they increase the number of fatal accidents, overturning accidents, single accidents without overturning, and collision with fixed objects [1]. All of these accident types can easily be associated with increased driving speeds as a function of risk compensation. Consider then ESC which seems to reduce the number of accidents of all accident types except accidents with pedestrians/bicyclists/animals [3]. It could be regarded as a paradox that ESC seems to have such unambiguously positive effects on accidents, which was not the case with ABS. *Behavioural adaptation* is also a main concern, but should be understood as a wider phenomenon than risk compensation as the latter should be regarded as a special case of the former [11]. An example: An outcome of increasing road lighting, besides reducing the number of accidents in darkness [2], is the attraction of more female drivers and more elderly drivers, possibly because these groups feel more secure by driving on lit roads at dark times of the day and because drivers who have vision problems naturally *see* better in darkness when roads are lit [6]. We will label this outcome behavioural adaptation, rather than risk compensation. This example illustrates that a main difference between compensation mechanisms adaptation mechanisms is that risk compensation would probably be more a product of unconscious processes of decision-making associated with automated driving, while behavioural adaptation may be a product of more strategic decisions, i.e. appraisal processes that involve consciousness and strategic thinking [7].

2.1. Predicting Outcomes of ITS: Seven Hypotheses

In general, a given ITS may represent a feeling of control, a limitation or an enhancement of the “window of opportunities”, a source of distraction, or an element which interferes with the process of learning appropriate schemes that govern risk monitoring. More specifically, the following hypotheses of effects of ITS are predicted and based on the Risk Monitor Model (RMM) described in [7] [8]:

- Hypothesis 1: If a car with a given ITS X *provides a better feeling of control* compared to a car without system X, the assumed accident risk reduction feature of system X might be compensated by a change in driver behaviour, for example by increased driving speeds.

- Hypothesis 2: An accident *increase* is predicted when an ITS enhances the 'window of opportunities', as with ABS for certain accident types.
- Hypothesis 3: An accident *decrease* is predicted when an ITS reduces the 'window of opportunities', as with ESC, ISA, Alcolock,
- Hypothesis 4: An accident *increase* is predicted with an IVIS when it is dissociated from primary driving tasks, by increasing the frequency of distractions, as with the use of mobile phones and its inherent applications.
- Hypothesis 5: A driver environment filled with too many warning systems may interfere with and deteriorate learning processes of the dangers in real traffic.
- Hypothesis 6 – Acceptance/Reliance: System X must perform better than the driver. If it fails – it will be abandoned by the driver.
- Hypothesis 7 – ITS addressing evolutionary limitations of risk monitoring as for example judging speed changes of the preceding cars, or looking for objects in dead angles, is predicted to reduce the number of accidents.

3. SYSTEMS CONSIDERED AND LEVELS OF IMPLEMENTATION

The present paper considers the following eight driver support systems regarding their potentials to reduce the number of fatalities: Intelligent Speed Adaptation (ISA), maximum speed governor, Alcolock, seat-belt lock, sleep/fatigue warning system, programmable, electronic ignition lock ("Smartcard"), adaptive cruise control (ACC) and electronic stability control (ESC) [9]. Estimates of lives saved are for the most part based on in-depth investigation of fatal accidents that may have been prevented if respective systems had been installed in the cars when the accident took place.

The Norwegian Public Roads Administration (NPRA) wanted estimates of driver support systems with potentials of reducing the number of fatalities at different levels of implementation. The levels of implementation were defined according to the following groups:

- Drivers 18 – 20 years of age
- Drivers 18 – 24 years of age
- Professional drivers
- All drivers (and passengers in some cases)

For some of the systems the NPRA wanted to estimate the effects in specific groups of drivers known to have high risk of being involved in fatal accidents. ISA, maximum speed governor for drivers convicted for speed violations, and effects of Alcolock for drivers convicted for drunk driving, would be of specific interest in this regard.

4. ESTIMATION METHODS

Regarding studies of the present driver support systems there are hardly none – except for ESC – which have been evaluated extensively on basis of accidents in real traffic [2] [3]. In absence of this, it has been necessary to base most of the estimations on ex ante or proxy methods – i.e. methods using data and assumptions as if the systems would have been used in real scenarios. All driver support systems are treated separately where assumptions, data bases and estimation methods for each of the systems are elaborated in detail in [9], but a short presentation of the estimation methods is also given here. One important source of information regarding the basis of estimates has been data from in-depth analysis done by NPRA's regional Accident Analysis Groups where the numbers of fatalities in Norway 2005-2010 are distributed according to accident types [10]. The distribution is presented in table 1.

Table 1: Number of road fatalities in Norway 2005-2010 distributed according to accident types (source: [10])

Accident types	Number of killed in road traffic						Total	
	2005	2006	2007	2008	2009	2010	2005-2010	%
Same direction	5	4	10	9	4	6	38	3
Head-on	90	105	104	84	87	82	552	40
Junction	19	19	15	22	13	14	102	7
Pedestrian	30	36	23	31	26	24	170	12
Run-off-the-road	74	70	74	97	77	69	461	34
Other accidents	6	10	6	12	5	13	52	4
Total	224	244	232	255	212	208	1375	100

The number of studies on ISA and its effects on accidents is limited, only one has been found [26]. In this study, however, the number of accidents in the before-period among drivers using ISA was much lower than in the control-group with the consequence that ISA seemingly increases the number of accidents compared to controls not using ISA. This increase was regarded to stem from a regression-to-the-mean effect from an accident-level which was abnormally low in the before-period [9]. As an alternative, the effect of ISA was estimated ex ante: Partly expressed by the *attributable risk* that can be allocated to speed violations and partly by the traffic volume that each of the groups represents [14] [15]. The theoretical ISA-system considered was a system that forces the vehicle to comply with the speed limits where driving takes place, i.e. the driver cannot override what is demanded by the ISA-system [12] [13]. *Attributable risk* measures the amount of the incidence that can be attributed to one particular factor by measuring the association between exposure to a particular factor and the risk of a particular outcome [27].

Professional driving in this context comprises all drivers who drive vehicles as part of their profession, as with taxi- and bus-drivers, as well as drivers who drive extensively when carrying out their occupation, as with specific groups of craftsmen. Regarding professional driving we have information of the traffic volume, i.e. total number of kilometers driven which is carried out by professional drivers. This is estimated to be 15% of the total traffic volume [14]. A second method which is used as an alternative in some cases is data from the accident register of Statistics Norway (www.ssb.no) which states the codes of vehicles which are used by drivers in the carrying out of their profession.

Regarding maximum speed governor the effects are based on an assumption that the set point of maximum speed is 110 km/h and that all driving speeds of 40 km/h above the speed limit zones of 80, 90 and 100 km/h are eliminated by a maximum speed governor [10] [16].

The effect of Alcolock is based on the attributable risk of drunk driving and to a situation where 98 per cent of drink driving can be prevented – the missing 2 per cent then attributed to Alcolock malfunction [17] [18] [19].

By a ”seat-belt lock” is meant a system which prohibits the vehicle to start before all seat-belts are used and locked in all seat positions where people actually sit [20]. Estimates of survival when using a seat-belt vary between seating positions. Estimates from the Handbook of Road Safety Measures, which are based on meta-analysis, are used and applied on fatal accident data from the regional Accident Analysis Groups of the NPRA in 2005-2009 regarding the number of drivers and passengers not using seat-belts [2]. The percentage of non-users in fatal accidents 2005-2009 was 43% [21].

A “smartcard” is in this context a programmable ignition key, as with Ford’s “MyKey”-system, which comprises options of applying specific measures for drivers and passengers (www.media.ford.com; http://ifa2011.fordmedia.eu/, www.ford.com). The specific MyKey-options records none-use of seat-belt, ISA, audio-system blocking, and an automatic emergency call in case of accidents. The potential, total effect of a MyKey-system cannot be calculated, except for an estimate of MyKey’s automatic emergency call system which seems analogous to the eCall system. The outcome of a potential eCall-system has been estimated by a Finnish in-depth study [22].

Regarding the remaining three driver support systems, i.e. warning of fatigue/sleeping-at-the-wheel, and adaptive cruise-control (ACC), the methods of estimation are quite the same for all three systems as they are all based on fatal accident data from the regional Accident Analysis Groups regarding assumptions of contributing causes in respective types of fatal accidents. The effect of ESC is based on estimates from meta-analysis done in the Handbook of Road Safety Measures, which are all based on data from accidents in real traffic [2] [3] [10] [21] [23].

5. RESULTS

The most effective system is estimated to be ISA with a potential of saving 41 lives per year, the least effective system is a maximum speed governor with an estimated 8 lives saved pr year. Estimates of lives saved for the other seven systems vary between 14,9 and 37,5 lives saved per year [9]. A presentation of saved lives as percentages (table 2), may be more relevant for other countries, but the basis of estimation is again the total number of road fatalities in Norway 2009-2010.

Table 2: Estimations of lives saved according to selected driver support systems. Percentages. (Basis of estimation is the average number of fatalities in Norway 2009 – 2010 = 210 fatalities)

System Levels	ISA	Max Speed Governor	Alco-lock	Seat-belt lock	Fatigue/ sleeping warning	Smart-card	ACC	ESC
All/All drivers	19,6	3,8	16,3	13,9 *	7,1 (50%)	(3,0) **	17,9	14,7
Young drivers 18-20 years	2,3	-	-	2,1 *	-	-	-	-
Young drivers 18-24 years	5,0	-	-	3,6 *	-	-	-	-
Professional drivers (method 1)	3,0	-	-	1,5	1,1 (50%)	-	2,7	2,2
Professional drivers (method 2)	-	-	-	1,4	0,4 (50%)	-	-	-
Convicted drink drivers			2,2					
Speed violators	0,1	-						

Estimating effects of professional drivers by method 1 means using the amount of traffic volume. Method 2 means using Statistic Norway (SSB) vehicle codes as basis of estimation

Warning system fatigue/sleep 50%: means prevention of 50% of the accidents

"-" means "calculation basis is missing". Grey color means: "Calculation not relevant"

*) Include drivers and passengers **) Considers only the option of automatic emergency call (Fords"MyKey" has several options)

The most effective driver support system is ISA with an estimated effect of 19,6 % lives saved per year, the least effective system is a maximum speed governor with an estimate of 3,8 lives saved per year. Regarding the remaining systems the estimates vary between 7,1 % and 17,9 % lives saved per year when the basis for estimation is all drivers. In some cases the effects on passengers are included.

It should be noted that all systems but sleep-warning systems, are regarded as limiting drivers' windows of opportunities. A sleep-warning system is a system that potentially may attract sleepy drivers who might trust that such a system would effectively warn them that they are about to fall asleep. Hence, two estimates are given: One where the potential increase of accidents and the potential and successful warning cancel each other out, and one where accidents caused by falling asleep are effectively prevented in 50% of the cases. The two methods applied, one based on the traffic volume estimated to be driven by professional drivers, the other based on official accident statistics, show outcomes of similar magnitudes, by 1,1% and 0,4%, respectively. These outcomes can be interpreted as a validation of the applied methods.

In addition to the eight driver support systems, the effects of eco-driving have also been considered. Eco-driving is in the present context defined as driving with lower revolutions per minute during acceleration, with increased torque as a consequence, lesser use of engine braking, and fewer gear-shifts. In sum, these behaviour changes reduce fuel consumption per kilometer driven by 6 % ($p < 0.05$). A tendency of a reduction in the number of accidents is reported, but no estimate is given [24] [25].

6. SUMMARY AND CONCLUSIONS

One consideration regarding driver support systems is whether a given system limits or hinders the driver in engaging in driver behaviours that are deliberate violations of traffic law. ISA, Alcolock, maximum speed governor, seat belt lock and Smartcard/MyKey are clearly in the category of limiting the driver's windows of opportunities. ACC and ESC are also appraised as limiting systems, but not necessarily of behaviour that violate traffic law and regulations. The only systems that in this context should be regarded as potentially increasing drivers' windows of opportunities are systems that warn the driver of falling asleep at the wheel. Such systems may increase the number of sleepy drivers in the road system and, hence, also increase the number of accidents if the systems fail to prevent drivers from falling asleep. Estimates of lives saved are for the most part based on in-depth investigation of fatal accidents that may have been prevented if respective systems had been activated. All systems reducing the windows of opportunities, or limiting driver choices, are likely to be unpopular among drivers. Consequently, it is unlikely that car manufacturers will introduce such systems which may need legal support to be implemented. Decision-makers may, however, hesitate to introduce the necessary regulations if the devices are unpopular among drivers.

7. REFERENCES

[1] Vaa, T; Penttinen, M; Spyropoulou, I: ITS and effects on road traffic accidents: State of the art, *IET Intelligent Transport Systems*, 1(2), 2007, pp 81-88.

[2] Elvik, R; Høye, A, Vaa, T; Sørensen, M. W. J: *The Handbook of Road Safety Measures, 2nd Edition.* Emerald Books, 2009.

[3] Høye, A: The effects of Electronic Stability Control (ESC) on crashes - An update. *Accident Analysis and Prevention* 43, 2011, pp 1148-1159.

[4] Marburger, E, A; Klöckner, J-H, Stöcker, U: *Assessment of the potential accident reduction by selected Prometheus functions.* Federal Highway Research Institute (BASt), Bergisch Gladbach, September 1989 (Pro-General/ Reports of the launcing phase).

[5] Aschenbrenner, K.M., Biehl, B., Wurm, G.W: *Einfluß Der Risikokompensation auf die Wirkung von Verkehrsicherheitsmassnahmen am Beispiel ABS.* Schriftenreihe Unfall- und Sicherheitsforschung Straßenverkehr. Bergisch Gladbach, Bundesanstalt für Strassenwesen (BASt). Heft 63, 1987, pp 65-70.

[6] Assum, T, Bjørnskau, T, Fosser, S, Sagberg, F: Risk compenasation – the case of road lighting. *Accident Analysis and Prevention,* 31 (5), 1999, pp 545-553

[7] Vaa, T: “Modelling Driver Behaviour on Basis of Emotions and Feelings: Intelligent transport systems and behavioural adaptations.” In Cacciabue, P. C. (ed): *Modeling Driver Behaviour in Automotive Systems – Critical Issues in Driver Interactions with Intelligent Transport Systems.* London, Springer-Verlag London Limited, 2007, pp 208-232.

[8] Vaa, T: “Drivers’ information processing, decision-making and the role of emotions: Predictions of the Risk Monitor Model.” In: Cacciabue, P.C; Hjälmdal, M; Lüdtke, A; Riccioli, C (eds): *Human Modeling in Assisted Transportation: Models, Tools and Risk Methods*. Milano, Springer Verlag, 2011, pp 23-32

[9] Vaa, T; Assum, T, Elvik, R: *Driver support systems: Estimating road safety effects at varying levels of implementation.* TOI-report 1202/2012. Oslo, Institute of Transport Economics, 2012. (In Norwegian with English summary).

[10] Haldorsen, I: *In-depth analysis of fatal road accidents in the year 2010*. Oslo, Norwegian Public Roads Administration, 2011 (in Norwegian).

[11] Vaa, T. “Psychology of Behavioural Adaptation.” In: *Behavioural Adaptation and Road Safety: Theory, Evidence and Action.* C.M.Rudin-Brown and S.L.Jamson (Eds). Boca Raton, CRC Press, Taylor & Francis Group, 2013, pp 207-226.

[12] Almqvist, S. *Loyal Speed Adaptation. Speed limitation by means of an active accelerator and its possible impacts in built-up areas*. Bulletin 232. Lund, Lund Institute of Technology, Department of Technology and Society, Traffic Engineering, 2006.

[13] Lai, F., Carsten, O., Tate, F. How much benefit does Intelligent Speed Adaptation deliver? – An analysis of its potential contribution to safety and environment. *Accident Analysis and Prevention 48*, 2012, pp 63-72.

[14] Vågane, L., Rideng, A: *Transport in Norway 1946-2010.* TOI-report 1165/2011. Oslo, Institute of Transport Economics, 2011 (in Norwegian with English summary).

[15] Elvik, R. A re-parameterisation of the Power Model of the relationship between the speed of traffic and road safety. *Accident Analysis and Prevention 5*0, 2013, pp 854-860.

[16] Elvik, R. A restatement of the case for speed limits. *Transport Policy*, 17, 2010A, pp 196-204.

[17] Bjerre, B. and Thorsson, U: Is an alcohol ignition interlock programme a useful tool for change the alcohol and driving habits of drink-drivers*? Accident Analysis & Prevention* 40, 2008, pp 267-273.

[18] Elvik, R. *Development of risk of apprehension of traffic violations.* Report 1059/2010. Oslo, Institute of Transport Economics, 2010B.

[19] Elder, R.W; Voas, R; Beirness, D; Shults, R.A; Sleet, D.A; Nichols, J. L; Compton, R: Task Force on Community Preventive Services: Effectiveness of Ignition interlocks for Preventing Alcohol-Impaired Driving and Alcohol-Related Crashes. A Community Guide Systematic Review. *Am J Prev Med*, 40(3), 2011, pp 362-376.

[20] Elvik, R., Mysen, A. B., Vaa, T: *Handbook of Road Safety Measures.* Oslo, Institute of Transport Economics, 1997 (3rd Norwegian edition).

[21] Haldorsen, I; Rostoft, M. S: *In-depth analysis of fatal road accidents 2005-2009 – With special focus on the year 2009.* Report 2010:2617. Oslo, Norwegian Public Roads Administration, 2010 (in Norwegian).

[22] Virttanen, N: *Automaattisen hätäviestijarjestelmän vaikutukset onnettomuustilantcessa.* Helsinki: AINO, julkaisut 14/2005.

[23] Nordbakke, S., Sagberg, F: Sleepy at the wheel: Knowledge, symptoms and behaviour among car drivers. *Transportation Research Part F*, 10, 2007, pp 1-10.

[24] Parkes, A.M. ,Reed, N: TRUCKSIM: preliminary results from cohort study in England. *Proceedings of HUMANIST Conference on Application of New technologies to Driver Training*, Brno Czech Republic, January 2005.

[25] Reed, N; Cynk, S., Parkes, A: *From research to commercial fuel efficiency training for truck drivers using TruckSim.* Wokingham, UK, TRL Driver Behaviour and Training, 2009.

[26] Varhelyi, A., Hjälmdahl, M., Hydén, C., Draskóczy, M: Effects of an active accelerator pedal on driver behaviour and traffic safety after long-term use in urban areas. *Accident Analysis and Prevention,* 36, 2004, pp 729-737.

[27] Everitt, B.S: *The Cambridge dictionary of statistics. Second edition.* Cambridge, Cambridge University Press, 2002.