AN EXAMINATION OF SAFETY IMPACTS FROM PROMOTIMG E-SAFETY APPLICATIONS IN ISRAEL

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Introduction

In road traffic, extensive use is already being made of modern information and communication technologies, both at the roadside and in the vehicle itself. These technologies are collectively known as Intelligent Transport Systems (ITS). A subsection of ITS related to road safety applications is called electronic safety (e-safety). It is a common belief today that future road safety progress in the advanced countries will be associated with a massive application of e-safety systems. However, given the variety of systems being developed in the world and the uncertainty of their safety effects, practical questions rise as to selecting the e-safety systems to be promoted in a country. Thus, a study was commissioned in Israel, having two main goals:

1. To map existing e-safety systems in the world and to review their safety efficiency as appears in studies from the latest years.
2. To assess expected safety effects from promoting selected systems in Israel.

Review of e-safety systems and international knowledge

Having reviewed the literature from the last decade, a summary of 22 systems was provided. Table 1 presents the different systems reviewed on the study.

Table 1 - systems reviewed on the study

Acronyms	System name	Description
ESC	Electronic Stabilization Control	When the system identifies a critical driving situation it stabilizes the vehicle and prevent skidding.
ABS	Antilock Braking System	Prevents the vehicle wheels from locking during hard braking.
ISA	Intelligent Speed Adaptation	Alerts or intervenes when the speed exceeds the locally valid legal speed limit.
CSW	Curve Speed Warning	Alerts the driver when approaching a curve too quickly.
LDW	Lane Departure Warning	Alerts the driver when leaving the lane without signaling.
LCA	Lane Changing Assistance	Alerts the driver when there is an obstacle in the lateral and rear area of the vehicle, including the blind spot area.
LKA	Lane Keeping Assistance	Similar to LCA but the driver is actually assisted by an active steering wheel trying to intervene in order to keep the vehicle on a correct path within the lane.
ACC	Adaptive Cruise Control	Automatically adapt the vehicle speed to the vehicle driving in front
FCW	Forward Collision Warning	Alerts when the driver does not keep a safe distance from the vehicle ahead and also when the driver brakes suddenly.
EBR	Emergency Braking	Detects obstacles ahead, alerts and brakes automatically.
PCV	Pre-Crash Protection of Vulnerable Road Users	Detects vulnerable road users and employ fully automatic emergency braking when collision is unavoidable.
AFS	Advanced Front Lighting System	The headlight is directed into the bend as soon as the vehicle begins cornering.

NIW	Night Vision Warn	Shows the area in front of the vehicle with a longer range of visibility than with the normal headlight and detects and warns for obstacles.
DDM	Driver Drowsiness Monitoring and Warning	Alerts when the driver shows symptoms of drowsiness.
WLD	Wireless Local Danger Warning	Detects hazards and communicates the hazard information to other vehicles via vehicle-to-vehicle communication.
	Vehicle to Infrastructure Long Range Communication	Detects hazards and communicates the hazard information to other vehicles via vehicle-to- infrastructure communication.
	Vehicle to Vehicle Short Range Communication for Collision Avoidance	Processes vehicles location and speed data and alerts when there is a risk of collision.
	Vehicle to Infrastructure Communication for Red Light Warning	A speed recommendation will be given when approaching an intersection with traffic lights, to help the driver drive with appropriate speed, knowing in advance which situation he will be faced with when reaching the intersection. Also alerts when the driver seems to ignore the red light.
INS	Vehicle to Infrastructure Communication for Intersection Collision Warning	Warns the driver if he seems to violate a right-of-way and also if somebody else is expected not to give the right-of-way to the case vehicle
	Vehicle to Infrastructure Communication for Speed warning in dangerous road geometry	Alerts the driver when his speed is too high for the road conditions (by electronic sign).
IVDR	In-Vehicle Data Recorder	Monitors and analyzes driver behavior.
eCall	Emergency Call	Emergency automatic call that gives precise coordinates of the location of an accident to the emergency services.

In general, the systems can be classified into 4 major categories: in-vehicle systems (located in the vehicle and deals with skidding, brakes, speed, lane departure, distance keeping, lighting and drowsiness); vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication (deals mainly with hazard and collision warnings); driving monitoring (IVDR) and after accident (eCall).

Various studies around the world (mostly from Europe and USA) examined the safety potential of the different systems. Table 2 presents the principle projects reviewed.

Table 2 - principle projects reviewed

Project/Study	Topics
eIMPACT	Assesses the effects of Intelligent Vehicle Safety Systems on traffic and safety.
SafetyNet	Development of a methodology to gather risk/exposure data and integrate it to disaggregated datasets
IMPROVER	Examination of the impact on road safety of the increasing use of sports utility and multipurpose vehicles; the impact of Cruise Control on traffic safety,

	energy consumption, and environmental pollution.
EuroFOT	Demonstrates how driver assistance systems can increase safety and fuel efficiency across Europe.
RITA Projects	RITA operates and finances studies that assess the safety impact of e-safety technologies.

The current study focused on the safety potential estimates of five selected systems, which were found more relevant to Israel: Speed alert (SA), Automatic emergency call (eCall), Lane Departure Warning (LDW), Forward Collision Warning (FCW), and In-Vehicle Data Recorder (IVDR).

Knowledge review of the five selected systems

Intelligent Speed Adaptation Systems (ISA)

A large-scale field trial was conducted in Sweden in which 5,000 vehicles were equipped with advisory and intervening systems (Binding and Lind, 2002). 10,000 drivers were taking part of the trial. The study indicated that the average speed of the drivers was reduced, their driving became more homogenous, they entered junctions in a lower speed than they used to, they became more aware of the presence of pedestrians and they exceeded the speed limit less than before. That led to the conclusion that in 100% market penetration, the systems will reduce the numbers of injuries by 20% at urban roads.
The PReVENT project (Heinig and Kutzner, 2007) examined a speed alert system that combines Hot Spot Warning (alerts when the driver approaches hazardous sited on the road and advices desirable speed respectively). 64 drivers were divided into an experimental group (their vehicle was equipped with the system) and control group (without the system). Drivers who the system was installed in their car reduced their driving speed by 5%, what led to the conclusion that the system has the potential to reduce fatalities by 2.1%-10.7%, fatal accidents by 1.7%-8.7% and serious injuries accidents by 0.7%-3.6% depending on an expected market penetration between 13% and 65% in 2016. In addition to the reduction of speed, the system also leads to generally smoother ride. The number and duration of speed limit violations decreased by about 40% and the variance of speed was reduced by 15% which can be translated into 6.5% less accident risk.
According to the European project eIMPACT speed alert system (that also advices the driver what is the desirable speed according to different factors, e.g. curves, school areas, bad weather etc.) has the potential to reduce fatalities by 8.7% and injuries by 6.2%, assuming 100% market penetration (Wilmink et al., 2008).
A study that made use of data collected from ISA UK field trials and from the French project LAVIA found that Advisory ISA has the potential to reduce accidents by 2.7% and mandatory ISA has the potential to reduce accidents by 30%, assuming 100% market penetration (Lai et al., 2012).

Automatic Emergency Call (eCall)

Unlike other systems, eCall is active after the accident occurs. The role of the system is to help a quick and efficient rescue process of injured persons.
An in-depth study on the impacts of eCall was commissioned in four countries: UK, Netherlands, Finland and Hungary. The study made use of interviews, workshops, models, accidents analysis including fatal case studies and analysis of previous studies. The study concluded that the overall impact on fatalities of reduced rescue time as a result of eCall varies from a country to country (due to geography, rescue service performance and other factors). In Finland it was estimated as saving 4-8% of road fatalities and in the UK only 1% (Francsics et al., 2009).
Another study that assessed the safety potential of the system in UK, found that eCall has the potential to reduce fatalities by 3% per year and seriously injuries by 2%, in a penetration rate of 66% in 2020 (McClure and Graham, 2006).
According to the project SEiSS that based his conclusions on previous studies, 5% to 15% of road fatalities can be reduced to severe injuries and 10% to 15% of severe injuries can be reduced to slight injuries (Abele et al., 2005).

Assuming 100% market penetration, it was found on the project eIMPACT that eCall has the potential to reduce fatalities by 5.8% and to raise injuries by 0.1% (fatalities becomes injuries).

Lane Departure Warning (LDW)

A field operational test was conducted to assess the potential safety impacts, driver acceptance levels, and system maturity of an integrated LDW and CSW (Curve Speed Warning) system. 78 drivers participated on the trial. The use of the system led to 50% reduction of events in which the equipped vehicle came within 10 cm of a lane edge in steady-state lane-keeping situations. Lane changes performed without the use of turn signal were reduced by 43% on freeways and 24% on surface roads. The conclusion was that the use of the system changed the participant's lane-keeping and turn-signal behaviors and that may result in safety benefit (LeBlanc et al., 2007).
An integrated system that integrates LDW with FCW in heavy-track and LDW, FCW and CSW in light-vehicles was tested in a study. The integrated systems were introduced into two vehicle fleets: 16 light vehicles and 10 Class 8 tractors. The light vehicles were driven by 108 drivers for 6 weeks and the heavy trucks by 18 commercial-truck drivers for a 10-month period.
The findings indicated that use of the system resulted in improvements in lane-keeping, fewer lane departures, and increased turn-signal use. The system was found to reduce the frequency of lane departures (changing lane without signaling) among the light-vehicles, from 14.6 departures per 100 miles during baseline driving to 7.6 during the treatment condition (Sayer et al., 2011).
A study that made use of accidents data on USA between 2001 and 2003, analyzed accidents causes of large trucks (1070 accidents were analyzed). The study concluded that LDW could prevent 6% of the examined accidents (Kingsley, 2009).
Another study made use of accidents data in USA from 2004-2008 (Jermakian, 2011). The study analyzed data and classifies accidents according to nine general crash types, including changing lane. A lane-changing crash was defined as one where a vehicle driver struck another vehicle while intentionally changing lanes, merging or turning. The findings indicated that LDW has the potential to prevent or mitigate up to 3% of all accidents and 22.8% of fatal accidents.

Forward Collision Warning (FCW)

An experiment was conducted to determine the influences of an in-vehicle collision avoidance warning system on driver performance (Maltz and Shinar, 2004). A driving simulator was driven by 135 licensed drivers: 120 received alerts from the system when their headway to a lead car was less than 2 seconds, and other 15 drivers received no alerts (the control group). Drivers received 3 types of alerts: auditory, visual and multimodal. The system had varied levels of reliability, determined by both false alarms rate and failure to alert to short headway. The findings indicated that participants responded properly to the true alerts, slowing down in response to 86% of them, and slowed down inappropriately in response to only 16% of the false alerts. Alert interface had a significant effect on the driver's reliance on the system. Reliance was greatest on the auditory interface and least on the combined (visual and auditory) interface. The control group's headway was too short 12% of the time, similar results were obtained for the experiment group before they had been exposed to the system (during a warm-up drive in which the participants drove few minutes without receiving alerts). Pre-alert versus post-alert comparison of this participants showed that after their exposure to the system, they had short headway only 7% of the time. To summarize, alerted drivers spent less time on the danger zone (too short headway) than did drivers who did not receive alerts (Maltz and Shinar, 2004).
A study that made use of accidents data on USA between 2001 and 2003, analyzed accidents causes of large trucks (1070 accidents were analyzed). The study concluded that FCW could prevent 23.8% of the examined accidents (Kingsley, 2009).
Another study made use of accidents data in USA from 2004-2008 (Jermakian, 2011). The study analyzed data and classifies accidents according to nine general crash types. The findings indicated that FCW has the potential to prevent or mitigate up to 20% of all accidents and 2.6% of fatal accidents.

In-Vehicle Data Recorder (IVDR)

The first study that collected large-scale naturalistic driving data from vehicles equipped with Event Data Recorder (EDR) was "The 100-car Naturalistic Driving Study" carried out by NHTSA (Dingus et al., 2006). 241 equipped vehicles drove for a period of 18 months. Parameters such as acceleration, vehicle speed, vehicle headway, time-to-collision, and driver reaction time were recorded. The system reported events from 3 types: crashes, near-crashes, and other incidents, and showed the driver behavior previous to these events. It was found that drivers were more careful when driving with the system at the beginning, but they returned to their normal behavior as time went on. The system only collected data but did not provide any alerts or feedbacks to the drivers.

IVDR systems record driver's behavior also in normal driving situations thus can be used for the purposes of research, education and training.

Few studies were conducted at Israel in recent years to examine the impact of the system and feedbacks it provides on the driver behavior and consequently on safety (Toledo and Lotan, 2006; Musicant et al., 2007; Toledo et al., 2008; Toledo, 2011). Those studies examined IVDR that has been designed to monitor and analyze driver behavior in normal driving situations in addition to accident or pre-accident events. From the data captured by the system, risk indices were calculated to indicate on driving safety level. The conclusion was that the use of the system can have a positive impact on drivers' behavior and on safety; however, if drivers do not use the feedback from the system and make follow-up efforts, it will not have a positive effect on their behavior.

A study that made use of the risk indices was carried out among 103 drivers who drove with the system for 12 months (Musicant et al., 2007). The blind stage of the study lasted 2 months and the feedback stage lasted 10 months. The results showed positive connection between IVDR risk indices and accident involvement, which indicated on the ability of the system to predict future accidents involvement of the drivers. Exposure to the feedback generated by the system has a potentially high impact on accidents reduction with over 40% reduction in crash rates (but the connection was not significant for fault crash rates).

An evaluation of the changes in the risk indices showed a decrease in the average of the risk indices over the first 9 months of the study but it was not statistically significant from the 10^{th} month and on.

In a similar study 191 compact trucks, equipped with the system, drove by drivers for 9 months (blind stage 2 months; feedback stage 7 months). The results showed a statistically reduction of 38% in crash rates with the exposure to the feedback, but not in fault crash rates (Toledo et al. 2008).

In a study that was commissioned in Washington DC, the influence of IVDR on driving safety level of young drivers was examined (Farmer et al., 2010). 84 young drivers on the age of 16-17 (with driving experience between 0 to 15 months) drove for 11 months on equipped vehicles. The system recorded events of sudden braking and acceleration, speeding, nonuse of seat belts. The researchers concluded that a low monitoring by the parents affected the deterrence efficient among the teenage drivers and that in order to make a difference among young drivers driving, parental monitoring is required.

Toledo (2011) examined the impact of IVDR on driving behavior and potential accident risk reduction. On the trial, about 100 vehicles belong to Israeli Air Force base were equipped with the system, in which 400 drivers drove for a year. The experiment was designed in three stages. Initially drivers were not exposed to the system and no feedback was provided to them. Next, drivers were informed about the system and some drivers received periodic feedback from the safety fleet officer based on the information collected by the system. In the last stage, all drivers received periodic individual feedback reports. The study showed more than 20% reduction in events rate from the blind stage to the individual feedback stage. For drivers who received both types of feedback (officer and individual report) there was a reduction of 27% in events rate.

Assessment of expected safety effects of each system

The eIMPACT methodology (Wilmink et. al. 2008) served as a basis for the systems' evaluation.
The safety effectiveness of each system was examined by the value of casualties reduction derived from the use of the system.
The reduction of accidents/casualties is a multiplication of three components:
(A) Estimation of **accidents and casualties reduced** by using the system, assuming 100% market penetration;
(B) The number of accidents and casualties **relevant to the system**, observed in the past years, in the country;
(C) Estimation of the **market penetration** of the system, for a year considered (e.g. 2020).
The safety impact analysis made use of 9 mechanisms that reflects the possible effects of the systems on drivers' behavior and on safety, including intended and unintended impacts, positive and negative impacts. The 9 mechanisms are outlined as follows:

1. Direct in-car modification of the driving task: direct influence of in-car systems on driver attention and decision about actions (e.g. driving speed). The mechanism covers intended influences (e.g. driving speed) and unintended influences (e.g. distractions).
2. Direct influence by roadside systems: identical influences on the driver as the influences of in-car systems but more limited because the systems cannot control the vehicle or the driver action.
3. Indirect modification of user behavior: indirect influence on the driver's behavior in which the driver will adapt to the changing situation (e.g. change of headway in car following).
4. Indirect modification of non-user behavior: behavior change of non-equipped drivers by imitating the behavior of equipped drivers (e.g. decreasing driving speed due to the speed decrease of equipped vehicle ahead).
5. Modification of interaction between users and non-users: influences derive from the interaction between users and non users, including vulnerable road users.
6. Modification of road user exposure: changes in the amount of travelling (e.g. more or less, longer or shorter trips due to the use of the system).
7. Modification of modal choice: increased attractiveness of car driving due to the system may result in more car trips compared to public transport. Different travel modes have different accident risks, therefore any measure which influences modal choice, has also impact on road safety.
8. Modification of route choice: changes in the route choice due to the use of the system. Since different road types have different accident risks, route choice has an influence on road safety.
9. Modification of accident consequences due to quick and accurate crash reporting. This mechanism is more relevant to eCall.

For each one of the five selected systems the relevant influence mechanisms were chosen. Based on the available knowledge (previous studies and experts evaluations), the influences from each one of the relevant mechanisms were translated into percentages of change (decrease or increase) in the number of fatalities and injuries. The sum of those values of change gave the modification percentage for each system. The first mechanism is the most significant mechanism for most systems.

Each selected system affects different types of accidents. To properly relate the effect of the selected system on casualty reduction, accident statistics were classified in different types as follows:

1. Vehicle type (passengers/commercial).
2. Accident type (e.g. rear-end, head-on)
3. Road type (urban/rural/freeway)
4. Weather conditions.
5. Lighting conditions (day/night).
6. Accident location (junction/road segment).

The safety potential of the systems was calculated according to 100% market penetration rate and according to the predicted penetration rate for 2010 and 2020. For each year a scenario of low penetration rate was estimated, i.e. without incentives to use the system, and a scenario of high penetration rate, i.e. with incentives.
For the implementation of eIMPACT methodology in the present study, a workshop was held with experts from TNO (Netherland's Organization for Applied Scientific Research, one of the major partners of eIMPACT project).

On the present study, the safety potential was estimated in terms of the expected saving of accidents' fatalities and injuries in Israel, according to the multiplication of the three components (A) (B) (C) mentioned above.
(A) For the estimation of fatalities and injuries reduced by using the system, assuming 100% penetration, the following steps were conducted:
1. Determination of relevant accident types for LDW, FCW, eCall and road type for SA and IVDR.
2. Determination of the relevant mechanisms (out of the 9 mechanisms).
3. Setting casualties' modification factor for each mechanism according to accident/road type.
For each system, the relevant influence mechanisms were chosen. Based on the available knowledge (previous studies and experts evaluations), the influences from each one of the relevant mechanisms were translated into percentages of change (decrease or increase) in the number of fatalities and injuries. The sum of those values of change gave the modification percentage according to the relevant accident/road type.
For SA and eCall the modification factor was determined by the mechanisms were used on eIMPACT project.
For LDW, FCW, IVDR the modification factor was determined by estimations from the literature and a panel of experts.

(B) After determination of relevant accident/road types for each system, the relative share of fatalities/injuries was evaluated for each accident/road type, out of the total casualties from car accidents in Israel. The base year of the study was the annual average of car accidents' casualties in Israel for 2008-2010.

(C) The evaluation considered 3 scenarios of the market penetration of each system: 100% penetration rate, 50% penetration rate for 2015 and 80% penetration rate for 2020.

Findings

The results indicated a contribution of all five systems to road safety. Figure 1 shows each system's potential reduction of fatalities and injuries.

Figures 1 - potential reduction of fatalities and injuries

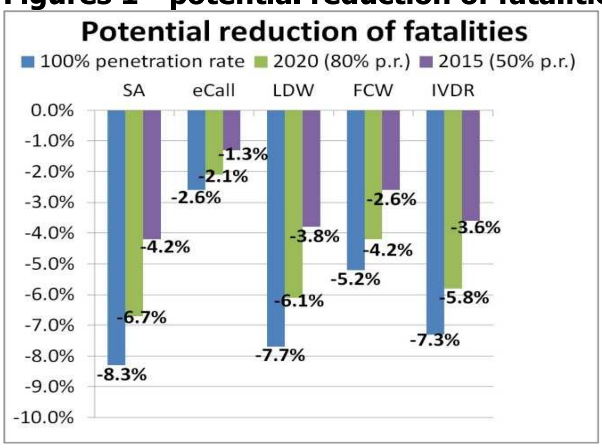

Fig. 1a

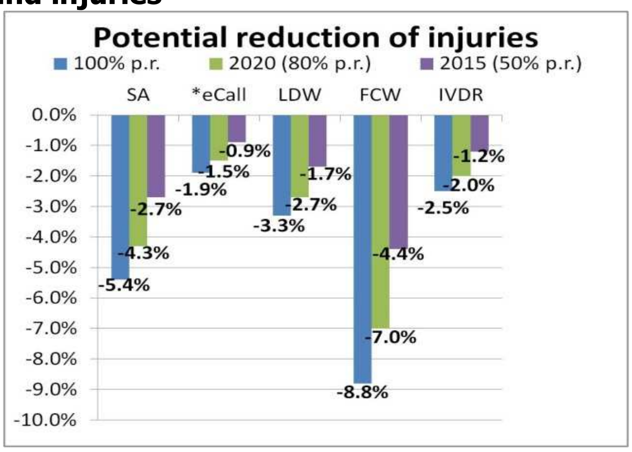

Fig. 1b * serious injuries only

The system that was found to have the highest potential to reduce fatalities is Speed Alert, with a potential to reduce 8.3% of fatalities, assuming 100% penetration rate. LDW and IVDR also have a high potential to reduce fatalities. The system that was found to have the highest potential to reduce injuries is FCW, with a potential to reduce 8.8% of injuries, assuming 100% penetration rate. Other systems showed lower potential to reduce injuries.
eCall was found to have the lowest potential to reduce casualties compared to the other systems, and also less effective in comparison to other countries . This is explained by the small country's size and relatively high distribution of emergency services throughout the country.

Discussion, Conclusions and further research

Relative to other systems, there are many studies worldwide that examined the safety potential of ISA systems, including field studies. In Israel there are no studies that examined the safety potential of the system. In this study SA is assumed to warn the driver when traveling at a speed above the limit, and consequently causes a change in behavior which leads to reduction of the actual speed and hence, reduction in accidents. The system was found to have the potential to reduce fatalities by 8.3% and injuries by 5.4% in road accidents, assuming 100% penetration. Estimates of similar magnitude were obtained in other studies worldwide.

Various studies that investigated the eCall system efficiency showed that the system has potential to reduce the number of fatalities and seriously injured in road accidents. The percentage reduction is based on data analysis and expert assessments, and not on field studies.
In the present study it was assumed that eCall system impacts mainly non-urban road accidents only. Higher reduction coefficients are attributed to single vehicle accidents. In Israel there are no studies that examined the safety potential of the system.
The system was found to have the potential to reduce fatalities by 2.6% and injuries by 1.9% in road accidents, assuming 100% penetration. These estimates are low compared with results of other studies around the world, mainly because of the short distances and wide deployment of rescue forces relative to other countries.

Various studies indicate that the LDW system has the potential to reduce the number of accidents caused by lane deviation. Field experiments showed decreased frequency of conflicts, which could be translated to a reduction in accidents, but this has not translated to percentage reduction. In Israel there are no studies that examined the safety potential of the system.
In this study it was assumed that the LDW system alerts when the driver crosses a lane without signaling. Therefore, the system has an impact mainly in interurban roads.
The greatest impact of the system is expected on side accidents; a lower impact but still significant is expected on front - side collisions and single vehicle accidents. The system was found to have the potential to reduce fatalities by 7.7% and injuries by 3.3% in road accidents, assuming 100% penetration.

There are few studies in the international literature that examined the safety potential of FCW. These studies found a relatively high potential to prevent road accidents, but the conclusions are based on analysis of accident data and expert assessments, rather than on field studies. In Israel there are no studies that examined the safety potential of the system.

In this study it was assumed that the FCW system alerts when the driver does not keep a safe distance from the lead vehicle, or there is an obstacle in front of the vehicle, which may also contribute to prevent pedestrian accidents.
The biggest impact is expected on the system's front-rear accidents and also on pedestrian injury accidents or cyclist in urban areas. The system was found to have the potential to reduce fatalities by 5.2% and injuries by 8.8% in road accidents, assuming 100% penetration. The reason for greater savings in injuries, relative to the number of deaths is due to the percent reduction in front – rear collisions.

IVDR system monitors the driver's data and enables reporting and provides safety management information and feedback for a particular fleet. Evaluation studies of such systems show that the system contributes primarily to reducing speed.
Due to reliance on the speed issue, the potential impact of the system is attributed to road deaths and casualties only on road sections. The system was found to have the potential to reduce fatalities by 7.3% and injuries by 2.5% in road accidents, assuming 100% penetration.

The quantitative findings of the various systems rely mainly on expert assessments. It is important to monitor the various experiments performed in the world, but also important to perform field tests in Israel.
All estimates were calculated assuming independence between the different systems. This means that the contribution of the specific system is evaluated against the basis situation without any other system. Therefore, further research is needed to examine the effects of combined systems, such as an integrated system of FCW and LDW, and integration of other systems.
This study focused on five systems. It is possible to expand the current research and perform estimates of additional systems, applying the same methodology developed in this study.
It is also important to examine drivers' acceptance of various systems and their willingness to pay and to use those systems.

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