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The Accuracy and Timing of Pedestrian Warnings at Intersections: the Acceptance from Drivers and their Preferences

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Abstract—**The safety of vulnerable road users at traffic intersections is critical. Driver assistance systems can improve safety but have to rely on accurate detection of hazardous situations. Given the complexity of pedestrian movement, detection of pedestrian presence and prediction of their behaviour are not always without error. Drivers' attitude towards such errors is an important issue for the effectiveness of the system. An online questionnaire survey has been carried out to investigate drivers' acceptance of the system under different reliability and accuracy configurations. The results show that safety warnings of pedestrians are generally found to be useful, although false positives and false negatives tend to reduce its pleasantness. The system is found to be most useful for right turn movement at a busy intersection, compared to through movements and quiet intersections. Drivers also find false alarms more acceptable than false negatives. In terms of timing of the warning message, drivers prefer to receive it earlier rather than later.**

I. Introduction

OVER the past few years the research on intersection safety systems has become very intensive. An example is the Intelligent coopeRative Intersection Safety (IRIS) system, being developed in the European research project SAFESPOT [1]. By means of vehicle-to-infrastructure (V2I) communication and enhanced roadside sensors, IRIS tracks and analyses the movements of individual road users including vulnerable road users (VRU) [2]. When a safety-critical situation is identified, the road users are warned for the potential danger. As drivers get warned when a collision with crossing VRUs is likely to arise, the safety of VRUs has been explicitly addressed by systems like IRIS.

The prediction of pedestrian behaviour in the current intersection safety systems is, however, very simplistic. This is mainly due to the complexity and uncertainty of pedestrian crossing behaviour at intersections, as well as possible sensing and tracking errors. In practice, predictions cannot be 100% accurate. This means that both false positives (false alarms; warning given but true risk does not exist) and false negatives (misses; no warning given while there is a risk) are likely to occur. The aim of this study is to investigate drivers' acceptance of pedestrian warnings, given that those warnings are not 100% accurate.

Firstly a literature review (Section II) is carried out on the sensors and algorithms used to detect pedestrians, as well as appropriate modelling approaches to determine the crossing intentions of pedestrians near intersections. The detection is not always 100% accurate; there are also uncertainties in the crossing behaviour. User acceptance of the warning system is then at question. An internet questionnaire survey (Section III) is conducted to study drivers' acceptance of the system under different system setups (differing in terms of accuracy and message timing). The survey results, as well as their implications, are discussed in Sections IV and V. Section VI concludes the paper with some discussions.

II. Background

A. Pedestrian Detection

In terms of the accuracy in pedestrian detection, the detection algorithm plays a more important role than the type of sensor [3]–[9]. In the European projects PROTECTOR [4] and SAVE-U [5] a combination of different sensors is used to improve the reliability of the pedestrian detection. There is a trade-off between the rate of pedestrian detection and the rate of false alarms, as shown by the receiver operating characteristic (ROC) curve in Fig. 1 [3].

VRU protection systems can be classified into three categories [5]: passive systems, which reduce the accident severity when a crash takes place; active systems, which reduce critical traffic situations in their criticality by using active components; and, preventive systems, which aim to avoid crashes or reduce their severity at an early stage. The safety systems developed in PROTECTOR and SAVE-U are active rather than preventive. The detection range of their sensors is normally between 12m to 40m, which is too short for a preventive system like IRIS. In order for drivers to be able to react in a more comfortable way (instead of hard braking), a longer detection range is required for the sensors.

Communication techniques also play a role in pedestrian detection. A difference between PROTECTOR, SAVE-U

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and IRIS is that in IRIS, V2I communication is used instead of V2V (vehicle-to-vehicle). Roadside detectors (camera, laser scanner, radar etc.) usually have a longer range because the reconciling distance between sensor and target increases significantly. There is also a difference in terms of the detection angle. Roadside sensors are usually pointing down towards the intersection, whereas vehicle-mounted sensors detect pedestrians in front of the vehicle at an almost horizontal angle. The detection algorithms need also to reflect this difference.

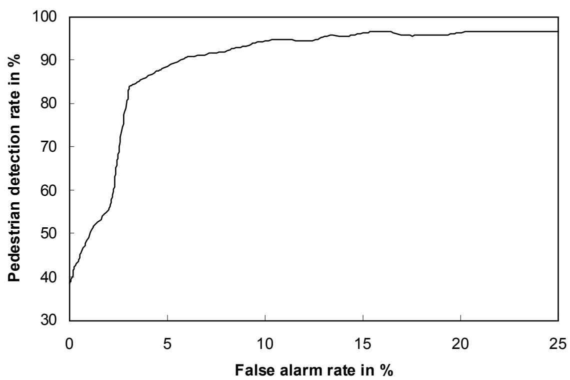

Fig. 1. The receiver operating characteristic (ROC) curve [3]. There exists a trade-off between pedestrian detection and false alarms: to achieve a higher pedestrian detection rate will usually incur a higher false alarm rate as a side effect.

B. Pedestrian Movement Prediction

There exists a great deal of uncertainty in predicting pedestrian crossing. The crossing action involves cognitive decisions which might not be obvious or observable. It includes factors such as personal perception of risks, which is difficult to predict. Previous studies on pedestrian behaviour (e.g. [10]) mostly concern walking and following, without explicitly addressing the crossing at intersections. A few recent developments in pedestrian warnings systems [11]-[13] base their warning solely on the VRU's position and heading direction in comparison to the vehicle's current path. Due to the dynamic nature of pedestrian behaviour, such a movement prediction method is not very reliable. It may result in many false alarms or even false negatives.

A more reliable way of predicting pedestrian crossings is to incorporate the probabilistic character of pedestrian movement. For a pedestrian who is currently standing or walking near the intersection, the model needs to determine the instantaneous rate that a pedestrian will terminate his or her waiting time and start to cross the street. *Duration models* study the elapsed time until the occurrence of an event [14] and therefore can be applied to pedestrian crossing behaviour [15].

In duration models, the pedestrian's waiting time before crossing a street, t, is considered as a random variable. Its distribution depends on a number of exogenous variables ($\mathbf{R}_i$ for pedestrian i). The hazard function $\xi(t)$ describes the instantaneous rate of ceasing the waiting time (and thus starting to cross):

$$\xi(t,\mathbf{R}_i)=\bar{\xi}(t)f(\mathbf{R}_i,\chi).$$

Here $\bar{\xi}(t)$ is referred to as the underlying risk of hazard independent of $\mathbf{R}_i$; the non-negative function f describes the influence of $\mathbf{R}_i$, with coefficients χ. For a given time t, $\xi(t,\mathbf{R}_i)$ is an estimate for the instantaneous rate that a pedestrian will terminate the waiting and start to cross.

In pedestrian warning systems, some of the exogenous variables $\mathbf{R}_i$ can be detected by the sensors. Results from previous research [16] show that the most influential factors are: distance to the incoming car, time to collision, car speed and walking direction. Other variables such as gender and age, although useful, cannot be exploited yet by the model.

Another study [17] considers the pedestrian crossing behaviour as a result of the decision making process based on a few environmental variables. These variables include the number of lanes across the street (which determine the crossing difficulty), the presence of a central traffic island, as well as the traffic control systems (e.g. traffic signals for vehicles and pedestrians).

C. Driver Acceptance and Preferences

User acceptance is an important design factor for all driver assistance systems [18]-[20], not only for the potential penetration level (or market share) but also for the impact on pedestrian safety. The former is of particular interest to the manufacturers as it would affect the profit; the latter is dependent on whether the driver will follow the assistance.

The possible errors in pedestrian detection together with the uncertainties in pedestrian movement prediction indicate that the pedestrian warning system is not perfectly reliable. Drivers' acceptance or preference is then a relevant issue. In particular, we focus on the trade-off between false positives and false negatives, and timing of the warning message.

Pedestrian sensors and detection algorithms are based on a preset threshold (or confidence level). A higher threshold is associated with less false positives but more false negatives; vice versa. The same applies to the probabilistic pedestrian movement predictions. The confidence or certainty level of pedestrian warnings also changes over time, e.g. due to the changes in distance. An analogue can be made to weather forecast. The short future can be predicted with a higher precision than the future far away. Therefore warning of a potential danger well ahead of time is likely to suffer from more false alarms. From a driver's point of view, a warning well in advance gives more time for proper reaction, while too many false alarms would gradually reduce the driver's attentiveness to the warning.

III. QUESTIONNAIRE SURVEY

A. Questionnaire Design

A questionnaire survey is conducted to study drivers' acceptance of pedestrian warning systems. The survey focuses on the following two aspects: timing and accuracy of pedestrian warnings. The applicable scenarios are limited to those shown in Figure 2, namely right-turning and straight-crossing movements at a busy or quiet intersection.

The questionnaire consists of three groups of questions: general, acceptance, and choice questions. The general questions concern the respondent's gender, age, country of residence and driving experience. Two rounds of acceptance questions are presented, the first one immediately following a brief introduction on pedestrian warning system. The respondents are asked to rate the system on usefulness and pleasantness, and to indicate their willingness to use and pay for the system.

False alarm and false negatives are then explained to the respondents, followed by the choice questions where the respondents are asked to state their preferences in different system options. These options differentiate in the ratio of false alarms and false negatives, as well as timing of the warning. The questions are designed in such a way that a trade off is always present. The second round of acceptance questions is then presented to see whether the respondent's option has changed due to the presence of false alarms and false negatives.

TABLE 1
STATISTICS OF RESPONDENT (SAMPLE SIZE = 88)

Category	Group	Percentage (%)
Gender	Men	60
	Women	40
Age	18 to 24	25
	25 to 34	53
	35 to 44	11
	45 to 54	6
	55 to 64	5
	65 and up	0
Residence	Greece	49
	The Netherlands	38
	Others	13
Driving experience	< 3,000 km/year	32
	3,000 – 10,000 km/year	29
	10,000 – 25,000 km/year	28
	> 25,000 km/year	11

B. Respondents of the Survey

Passenger car drivers (mainly Dutch and Greek) are targeted for the web survey, which ran online from 18 December 2009 to 3 January 2010. Respondents were reached through e-mail contacts. They were also requested to forward the e-mail through their personal networks (snowball method).

In total 110 respondents answered the questionnaire. Only 88 of them finished the survey and are included in this analysis. Table 1 gives an overview on the characteristics of these 88 respondents.

Drivers of both genders are well represented, with slightly more male respondents than female ones. Drivers above the age of 35 are under-represented (22%), a common problem with open internet surveys. Several researchers involved in the SAFESPOT project also joined the survey, forming part of the 'Others' group in country of residence.

IV. MEASURING ACCEPTANCE

A. Vanderlaan-scale

The Vanderlaan-scale [21] consists of nine criteria related to the usefulness or pleasantness of the system. Two rounds of the Vanderlaan-scale take place: first to rate the concept of the pedestrian warning system (Question 5); then a second time when the respondent has become more aware of the system capabilities and the applicable scenarios (Question 22).

Fig. 3 gives the survey results on acceptance. In general, the system is rated as useful, but not very pleasant. The differences between Questions 5 and 22 are not huge but still quite considerable. As expected, respondents become more negative about the system once they become aware of the reliability issues (false alarms and false negatives).

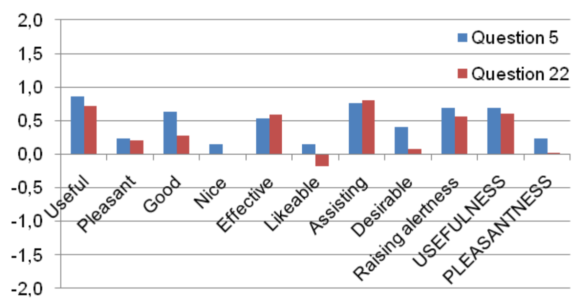

Fig. 3. Driver's acceptance of the system based on the Vanderlaan-scale: from -2 to +2 on usefulness (useful, good, effective, assisting, raising alertness) and pleasantness (pleasant, nice, likeable, desirable). Question 5 is before false alarms and false negatives are explained to the respondents; Question 22 after.

B. Willingness-to-pay

To the question whether they will buy such a pedestrian warning system, 57% of the respondents answered 'Yes, definitely', 'Yes' or 'Maybe'. Drivers under the age of 25, being male, and/or residing in the Netherlands are least inclined to buy. It might be because young men are generally very confident about their own driving skills and they argue that they are in no need of such system. As for country of residence, due to the generally flat terrain in the Netherlands,

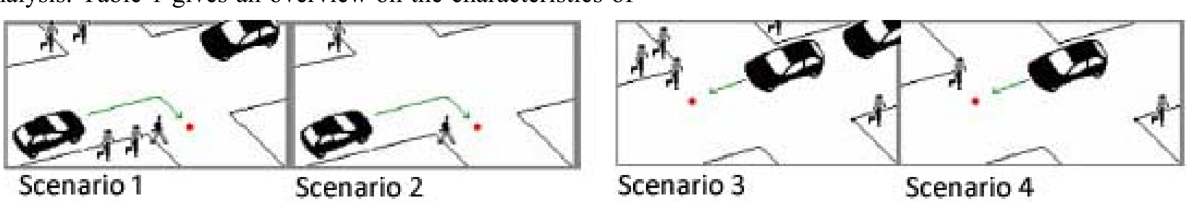

Fig. 2. The applicable scenarios for the pedestrian warning system: right-turn and through movements at a busy or quiet intersection.

drivers there usually have a better overview of intersections. They are therefore less likely to encounter safety-critical situations with pedestrians. The omnipresent cycle lanes also add a 'buffer' between the vehicle lanes and the sidewalk.

Those who are willing to buy the system are also asked about the price they are prepared to pay. The overall results are presented in Fig. 4. Male drivers are in general willing to pay more than female drivers. Respondents from Greece also offer a higher price than those from elsewhere.

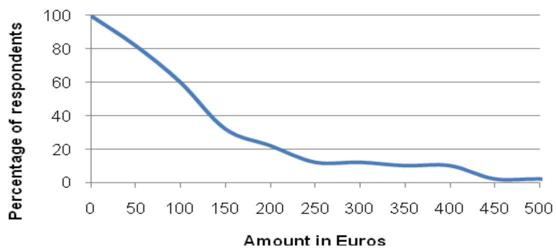

Fig. 4. The willing-to-pay price of drivers who want to buy a pedestrian warning system: 60% are willing to pay €100 or more; few drivers will buy the system when the price is above €250.

C. *Scenario Rating*

The respondents are also asked to rank the four scenarios in Fig. 2 by their importance in the pedestrian warning system. Overall, scenario 1 (right turn at a busy intersection) is rated the most important (by more than 50% of all respondents), whereas scenario 4 (going straight through at a quiet intersection) is rated as the least important (60% respondents).

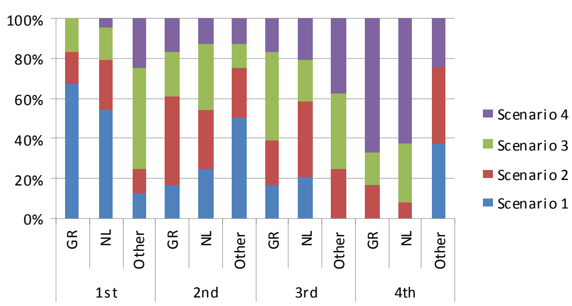

Fig. 5. Ranking of the four scenarios on their importance: scenario 1 (right turn at a busy intersection) is rated as the most important and scenario 4 (crossing a quiet intersection) the least important.

Fig. 5 shows the ranking results by country of residence. Respondents from Greece and the Netherlands follow more or less the same pattern. It is interesting to point out that respondents from the 'Other' countries (mainly SAFESPOT employees) choose scenario 3 (going straight through at a busy intersection) as the most important.

It has been argued that quiet scenarios are more important for a pedestrian warning system than busy scenarios, because it is more natural and mentally easier to adapt the speed for a crowd of pedestrians than for a single pedestrian. However, the survey results indicate that drivers feel the system is more useful for busy scenarios.

D. *False Positives versus False Negatives*

The questionnaire also includes five questions in which respondents had to choose between two options about false alarms and false negatives that involve pedestrians, vehicles and emergency vehicles. The results are shown in Table 2. Most respondents (86%) found a false alarm about a crossing pedestrian more acceptable than a false negative. It implies that the respondents understand that a false negative (i.e. a miss) is more critical than a false positive. Moreover, false alarms about crossing pedestrians were in general more accepted than false alarms about a car or an emergency vehicle violating the traffic light.

For the false negatives it is the other way around: false negatives about a pedestrian are less accepted than false negatives about a car or an emergency vehicle violating the traffic light. This is possibly due to the fact that a car is larger in size compared to a pedestrian and therefore easier to be identified by the drivers themselves.

V. Warning Accuracy and Timing

Several stated preference questions are included in the questionnaire to further study the respondent's acceptance on the accuracy and timing of the warning message. In each question a selection is to be made by the respondent between two alternative system designs: a system providing warnings for all potentially dangerous situations (Option 1 in Table 3) versus a system providing warnings only for very critical situations (Option 2). The choice questions further specify the likely amounts of false alarms and false negatives for each system, as well as the timing of the message. Table 4 provides an overview of the values of these variables. In comparison to Option 2, Option 1 has more false alarms, less false negatives (misses), and warnings more advance in time (message timing 1 or 2).

TABLE 3
Two Different System Designs of the Warning System

Alternative	Description
Option 1	"This system warns you for all potentially dangerous situations. This includes situations that are not critical (i.e. do not require emergency braking) but require just smooth braking."
Option 2	"This system will only warn you about very critical situations. In this way you might not be warned if a situation does not require urgent action."

TABLE 2
False Positives versus False Negatives: 'What is more acceptable for you?'

False alarm about a crossing pedestrian.	86%	14%	False negative about a crossing pedestrian.
False alarm about a crossing pedestrian.	57%	43%	False alarm about a car violating the traffic light.
False alarm about a crossing pedestrian.	55%	45%	False alarm about an ambulance violating the traffic light.
False negative about a crossing pedestrian.	39%	61%	False negative about a car violating the traffic light.
False negative about a crossing pedestrian.	43%	57%	False negative about an ambulance violating the traffic light.

Random utility theory is used to model respondents' preference in the system setups. The utility for an alternative i as perceived by an individual driver is a random variable; its mean value is given by the linear function:

$$V_i = \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i}.$$

Here the variables $x_{ji}, j = 1,2,3$ represent, respectively, the amount of false alarms (in ratio or percentage), the amount of false negatives, and timing of the message (see Table 4 for coding of the values). The parameters $\beta_j, j = 1,2,3$ are to be estimated by the survey data.

TABLE 4
SETUP OF STATED PREFERENCE QUESTIONS

Variable	Values
False alarms $x_{1i}, i = 1,2.$	- For option 1, amount varies between 2 out of 10 (0.2) and 3 out of 10 (0.3). - For option 2, amount varies between 1 out of 40 (0.025) and 1 out of 20 (0.05).
False negatives $x_{2i}, i = 1,2.$	- For option 1, amount varies between 1 out of 40 (0.025) and 1 out of 20 (0.05). - For option 2, amount varies between 1 out of 10 (0.1) and 1 out of 5 (0.2).
Message timing $x_{3i}, i = 1,2.$	The message will arrive at a time that: =1: "Releasing your gas pedal will be sufficient to avoid the collision." =2: "You will need to brake smoothly." =3: "You will need to brake immediately." =4: "An emergency brake will be needed, however you might not have enough time to avoid collision."

An individual chooses the alternative with the highest utility. A positive (negative) β for a variable means that the variable contributes positively (negatively) to the utility of the alternative; the alternative is thus more (less) likely to be chosen. Regression results of the choice model are shown in Table 5, based on maximum likelihood estimation. Besides the overall results, the sample data are also divided into smaller groups to investigate how personal characteristics might affect preferences and choices. As in Table 5, most of the estimated values do not pass the *t*-test at threshold level 1.96, indicating a poor performance of the choice model in predicting individual behaviour. However, the results are still meaningful in representing a general trend in the average choice behaviour and thus useful for system designers.

A. The Accuracy of Pedestrian Warnings

Drivers dislike both false alarms and false negatives (negative β_1 and β_2). This presents a technical dilemma for the system designer, as reduction in false alarms is usually associated with an increase in false negatives and vice versa (Fig. 1). Therefore the system needs to find the right balance between the two types of errors.

By comparing the absolute values of β_1 and β_2, it seems that, in general, drivers find false alarms more undesirable than false negatives (resulting in Option 2 (critical warnings only) being chosen more often by respondents. This is especially so for male, young drivers with a low annual mileage. However, preferences differ for other driver groups. In particular, drivers above the age of 35 and drivers of a medium annual mileage seem to dislike false negatives more than false alarms. These groups of drivers do not mind of being warned 'too often'.

At first glance the results here appear to contradict those from Section IV.D. Table 2 indicates that drivers realise the higher criticality of false negatives compared to false alarms. They are therefore more unacceptable of false negatives than of false alarms. However, when choosing the system settings (Table 3~5), drivers find false alarms more undesirable than false negatives. The reason is that from a psychological point of view, a false negative gives no warning and therefore no disturbance. This inconsistency suggests a conflict in interest (safety vs. comfort) and again presents a dilemma for system designers.

In terms of general acceptance, female drivers are more tolerant of possible errors (both false alarms and false negatives) in the warning system, compared to male drivers. Similarly, older drivers are more tolerant than younger drivers; Greek drivers more tolerant than Dutch drivers; experienced drivers more tolerant than normal drivers.

TABLE 5
REGRESSION RESULTS OF THE CHOICE MODEL

Group	β_1	β_2	β_3
overall	*-4.92*	-3.90	*-0.584*
Gender			
men	*-6.15*	-4.87	*-0.874*
women	-3.05	-2.56	-0.103
Age			
18 to 24	*-7.23*	-3.87	*-0.767*
25 to 34	*-4.62*	-4.22	*-0.570*
35 and up	-3.11	-3.36	-0.436
Country of residence			
Greece	*-4.86*	-3.44	*-0.682*
the Netherlands	*-6.60*	-6.29	*-0.596*
others	-0.416	1.14	-0.298
Annual mileage (km)			
below 3,000	*-5.70*	-2.93	-0.513
3,000 to 10,000	*-7.42*	-8.03	*-0.931*
10,000 and up	-2.54	-1.54	-0.394

Results were derived using the Biogeme software with the multinomial logit model assuming the dispersion parameter equal to 1. Numbers in italics passed the *t*-test at threshold 1.96.

B. Timing of Pedestrian Warnings

Most drivers prefer to receive the warning message earlier rather than later. This is evidenced by the negative β_3's for all driver groups. Male and young drivers want to be warned as early as possible. The same is true for drivers with a medium annual mileage. In contrast, female and experienced drivers seem not to mind 'surprises'.

Similar to the trade-off between false alarms and false negatives, there is also a trade-off between the errors and message timing. This has to do with the detection technology. The detection and prediction accuracy increases gradually as the distance to the object reduces. A prediction made at distance and well in advance is unlikely to be highly reliable; a highly accurate warning can probably only be confirmed when the time to collision is too short.

The numerical results here can help establish equivalence conditions between which drivers are indifferent. Based on the linear utility function and the results of $\beta_j, j=1,2,3$ in Table 5, it can be said (Table 6) that, for a normal driver, a reduction of the false alarm ratio by 0.12 is equivalent to a reduction of the false negative ratio by 0.15, or an earlier provision of the warning message from timing 3 to 2.

TABLE 6

EQUIVALENT CONDITIONS OF DRIVER PREFERENCES

Reduce the false alarm ratio by	Reduce the false negative ratio by	Provide the warning earlier
0.12	0.15	from 3 to 2
0.24	0.30	from 3 to 1

The results here are only indicative, especially so when the amount becomes large. This is because the utility function used in this paper assumes a linear form, where the difference between 80% and 90% accuracy is equal to that between 90% and 100%. This is certainly unreasonable in practice; a nonlinear (e.g. exponential) function can be utilised to solve the problem.

There also exist equivalence conditions in technology (e.g. Fig. 1). For instance, a prediction algorithm can be 70% accurate at timing 2 but 80% accurate at timing 3. For such case Table 6 implies that the former is more preferable for an average driver. Of course this preference would vary from person to person; the system design should accommodate flexible settings.

VI. CONCLUDING REMARKS

Most drivers find the pedestrian warning system useful but not really pleasant. This is mainly due to the accuracy issues in pedestrian detection and movement prediction. A system is less desirable if it gives many false alarms or false negatives. In terms of willingness to pay, young male Dutch drivers are among the group that is the least likely to purchase such a system. Older, female and Greek drivers are in general more willing to pay for the system.

Drivers find the system to be most useful for right turn movements at busy intersections. They find both false alarms and false negatives undesirable. Although drivers realise the impact of false negatives on safety, they feel annoyed to have too many false alarms. For timing of the warning message, drivers prefer to receive them early, so that they can adapt their speed at their own discretion. This suggests that future pedestrian warning systems should strive to provide the warnings as soon as possible, unless doing so would greatly increase the amount of false alarms and false negatives. The optimal balance in this trade-off can be tuned according to the driver's personal preference.

The results here are indicative rather than conclusive. To develop a robust pedestrian warning system, further research is necessary on the interaction between the system and the driver. With the rapid development in sensing and detection technology, the amount of false alarms and misses may be greatly reduced. Acceptance can change but the same trade-off has to be solved for individual drivers, possibly with a system that can 'learn' over time. Other areas of research include cost benefit analysis and the legal issues.

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