11AE-0113

Investigating the Improvement of the Localisation Propensity and Impact of the Emergency Vehicle Sirens

Stephen Boslem, John D. Moore, and Vassilis Charissis
Glasgow Caledonian University, School of Engineering and Computing,
Department of Computing and Creative Technology, Glasgow, UK

ABSTRACT

Rapid mobilization of emergency vehicles in the urban or rural road network presents a high probability of collisions and other related hazards to the rest of the drivers. Yet uninterrupted high speeds of the emergency vehicles through traffic are imperative for the successful patient transfer or negotiation of fire and flood emergencies. The utilisation of contemporary emergency vehicle sirens as an early warning system has proved inefficient and in some cases unsafe as the localisation characteristics of siren patterns combined with ambient noise has a detrimental effect on the average driver's ability to spatially define the position of the incoming emergency vehicle. This paper examines the inherent issues in the localisation of the incoming emergency vehicle audible warning systems and suggests a prototype system for faster localisation propensity of the incoming vehicle. Our system follows a two-fold approach that utilises a broader siren sequence, and pattern, as well as a Global Positioning System (GPS) broadcast through Radio Data System (RDS) in the close vicinity. In order to evaluate the system we contrasted the existing and proposed systems by simulating the siren localisation impact with the use of the Fire Service Emergency Cover (FSEC) modeling system in a predetermined emergency scenario positioned in a real environment in the Central Scottish Region between the major cities of Glasgow and Edinburgh where dense traffic is typically hindering the emergency services. Finally the paper offers a detailed analysis and discussion of the results and a succinct forecast of additional improvements for further investigation.

INTRODUCTION

Emergency vehicles' response speed is crucial to clinical outcomes in serious cases. The successful patient transfer is heavily related to the speed that the rescue vehicle can achieve through the traffic flow, particularly in traffic congestion bottlenecks. To this end, audible warning systems are integral to emergency vehicles in order to allow them to be located by other motorists and pedestrians [1, 2]. Yet, it is evident through previous work that the localisation characteristics of existing siren patterns combined with high levels of background noise can significantly affect the average driver's ability to accurately define the position and heading direction of the incoming emergency vehicle. This spatial misjudgment led to seven fatalities and 1,226 casualties according to the 2008 British road accident statistics [3].

Adhering to this grave accident statistic, this work aims to identify the inherent issues of existing emergency vehicle audible warning systems and explore areas of current audio technology to overcome these problems and improve siren localisation. Furthermore, the impact of improved sirens has been explored using advanced computer modelling techniques using Central Scotland Fire & Rescue Services Fire Service Emergency Cover (FSEC) modelling system. In particular the FSEC offered a test-bed for simulation, evaluation and prediction of the effect that the proposed sirens system might have upon the fatality rates, property damage figures and turn-out areas (areas reachable by emergency vehicles within a given timeframe). In turn we contrasted the results of the improved sirens to the existing siren system.

Overall, the paper is organised as follows: The next section focuses on the contemporary siren localisation issues. In turn the “Proposed solution” section offers a succinct overview of the prototype combinatory approach. The following section elaborates on the modelling and simulation scenarios used to evaluate the effectiveness of the proposed system in contrast to the existing siren auditory cues. In turn the comparative process results are presented in the following section. Concluding the paper outlines the limitations and considerations regarding the proposed system and presents a tentative plan for future work.

SIREN LOCALISATION ISSUE

Our inability to accurately locate the direction of an approaching emergency vehicle is directly linked to the siren patterns themselves. This fact was attributed to sirens deficiency towards the fundamental psychoacoustic requirements for a sound to be localised with any degree of accuracy [4, 5]. Human physiology plays a major part in this inability as the ear/brain system uses different auditory cues to localise sound. These cues known as Interaural Time Difference (ITD) and Interaural Intensity difference (IID) respectively, acquire their information from the simple fact that we have two receiving points (ears) separated by the head width [4, 6]. Hence, any sound that originates from either side of our head will arrive at the ear closest to it before reaching the other ear; it will also be louder at the closest ear.

Although we are enabled to perceive spatial awareness through the ITD and IID, these cues are also the source of spatial ambiguity for single frequency tones such as those present in existing siren patterns. This refers to the Cone of confusion [2, 5] where any given frequency can have numerous spatial positions that generate identical timing and intensity differences at the ear. Interestingly this issue was further analysed by psychomotor studies [6] which stated that position judgment of a sound image in a free-field can be corrupted by two different kinds of error, namely: localisation blur, which takes the form of a small random error in the region of five to twenty degrees in the judgment of a sound location, and front-back confusions depicted on the explanatory Figure 1. These are incorrect judgments when indicating whether a source is in the front or rear hemisphere.

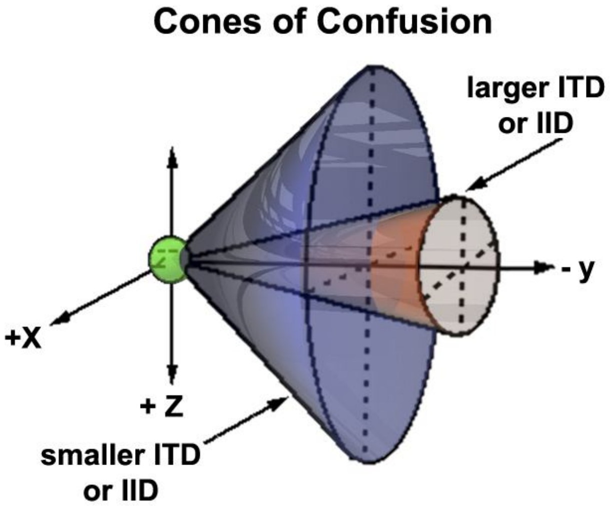

Figure 1 – Cones of Confusion as described by Wenzel et al. 1993.

These fundamental physiological issues have a direct impact to driver’s interaction with on-call emergency vehicles. Notably investigation of public reactions towards this issue revealed that audible warning systems were used 86% of the time, but this was not always in unison with warning lights [1]. Of those surveyed, nearly one third failed to detect the approaching emergency vehicle until it was less than 50m away. Even more astoundingly; 25% of the participants were completely unable to hear the audible warning systems on approach of the emergency vehicle. These figures again reinforce the limited effectiveness of current emergency vehicle audible warning systems [1, 5 & 7].

The aforementioned observations have clearly stated that the drivers could not differentiate the siren sound from the ambient noise at these distances, and evidently existing sirens are unable to overcome the background noise generated by driving on modern road networks rendering them completely unusable in some cases [7, 8, & 9]. Of all interactions with emergency vehicles, more than half of participants had to manoeuvre to let the vehicle pass, this led to the discovered wake effect, where one third of these manoeuvres placed a third party at risk [10, 11].

Towards this point we experimented and developed an improved siren system that could alert potentially a significantly larger number of motorists in a timely and safe manner. Ultimately this early and clear notification aims to increase the available time to manoeuvre safely, hence place fewer third parties at risk, reducing the wake effect, and allowing smoother passage of the emergency vehicles.

PROPOSED SOLUTION

The aforementioned observations suggest that a number of major obstacles must be individually tackled if future siren systems are to be localised with a greater degree of accuracy. Therefore, the proposed siren system utilises a different siren pattern that is easier for drivers to localise, as well as a Global Positioning System (GPS) broadcast through Radio Data System (RDS) warning system.

The first improvement aims to minimize or even eliminate spatial ambiguity inherent in existing single frequency siren tones. Therefore the siren pattern we use for this study is designed to produce short, wide-band noise bursts that are known to be easier sources to localize that single frequency sweeps. Earlier investigations suggested that signals which possess relatively few harmonics are less resistant to masking, and they also need to be presented at much higher signal-to-noise ratios than signals which are acoustically richer [4, 5]. Adhering to this observation, siren patterns should contain the broadest audible frequency range possible in a range between 20 Hz to 20 kHz. Notably existing siren patterns only cover roughly the region between 500 Hz to 1800 Hz, therefore is significantly more difficult for both motorists and pedestrians to accurately localise the source and direction of the sound [5, 6]. However the human hearing has a peak in sensitivity which reaches approximately 3500 Hz to 4000 Hz. As existing siren patterns do not generally exceed around 1800 Hz our proposed system aims to utilise a broader Hz bandwidth ranging from 400Hz to 4000Hz and utilise the ears increased sensitivity to this particular frequency band.

The second addition to the system is through Radio Data System (RDS) warning system which offers an auditory and visual warning to the driver circumventing the secluded shell of the vehicle interior and the potential environment noise. This second measure has been deemed essential for the drivers that cannot hear and locate even the improved siren. Evidently prior experimentations by the West Yorkshire and London Ambulance Services established that using broadband noise sirens resulted in an increase in average road speed of up to 10% [3, 6, & 11]. Similarly, our quantitative research process prior to the design of the proposed system revealed a consensus amongst emergency vehicle drivers that an increase in average road speed of 15-20% was achievable through the use of an RDS warning system.

This two-part system aims to alert the driver simultaneously externally (siren) and internally (RDS) to the vehicle. As such the lead-vehicles will have higher probability to identify on-time the alert and manoeuvre accordingly in order to support the safe high and constant speed of the emergency vehicles in an urban or rural environment. The preliminary experiments in the simulated environment demonstrated that a 30% speed increase can be achieved with the combinatory proposed system.

The predicted impact of increased road speeds on fatality rates and turn out times was examined using a simulation modeling method based on Central Scotland Fire and Rescue Services Fire Service Emergency Cover (FSEC) modeling system. This experimentation is further discussed in the following section of the paper.

MODELLING AND SIMULATION

In order to identify the potential impact of our proposed system on Fire-brigade emergency vehicles we designed a comparative evaluation which aimed to identify the benefits of drawbacks of the proposed siren system versus the existing system. This comparative study was tested in a simulated, controlled environment typically used for such type of experimentations. As such we were enabled to simulate safely the prototype system and investigate different simulation scenarios and uses of the suggested system. In particular, in order to examine the impact of the proposed emergency vehicle audible warning system, we utilised the designated computer modelling methodology, which is used by the Central Scotland Fire and Rescue Services Fire Service Emergency Cover (FSEC). This was essential for our research in order to resemble our hypothesis and testing process as close as possible to the existing standards. For the purpose of this work, Central Scotland Fire and Rescue Services base case model was used as the primary comparison point to explore the impact of the proposed emergency vehicle audible warning system. This base-case takes account of existing standard speeds on the road network and therefore is an accurate reflection of the average road speeds achievable by emergency vehicles using existing sirens. The experiment measured the distance that a fire-brigade vehicle can cover in a given timeframe of 8 minutes in an area around the town of Falkirk. Additionally the simulation measured the overall speed of the vehicles and the distribution of map coverage with and without the proposed system.

A feature of the FSEC road network allows individual road speeds to be modified. By altering the roads to reflect the increase in average speed possible through use of the broadband noise patterns and RDS warning system, FSEC will take these new speeds into consideration when running a new model. Subsequently, the predicted fatality rates and property damage figures of this new model can be compared against those of the base-case; allowing the impact of the proposed audible warning system to be shown. In addition to providing these prediction figures for comparison, FSEC has the ability to visually represent data on Ordnance Survey (OS) mapping as presented on Figure 2.

Figure 2 – This is a screenshot of an OS map of Central Scotland produced by FSEC. The yellow and red labels show the geographical locations of five fire stations in the area (Denny, Larbert, Falkirk, Bo'ness and Linlithgow)

SIMULATION RESULTS

An initial appraisal of the results presented by the comparative study can be attempted through the performance in area coverage of the simulated emergency vehicles with and without the use of the proposed system. Furthermore the FSEC modelling results demonstrated that as the average road speeds of emergency vehicles increases, predicted fatality rates and property damage figures decrease, as presented in the following figures.

To this point it has to be noted that the produced simulation and results do not take into account the possibility of road traffic collisions involving emergency vehicles on the roads. As emergency vehicles reach greater average speeds, there is a higher risk of collision; yet the simulation shown that localisation is improved as a result of broadband noise patterns. Additionally our quantitative research driver's subjective feedback suggested that the emergency vehicle drivers feel that road safety would be improved with use of this advanced warning system and their work related hazards can be significantly reduced. Nevertheless in this paper we are focusing on the potential benefits and drawbacks of the proposed system in relation to the maximum speed and area coverage that the emergency vehicles can reach.

Notably the benefits of the 30% increase in road speed achievable through the proposed system have a direct positive impact in the array of coverage with a substantial extension to the 8 minute turn-out area of Falkirk fire station. Figures 3 and 4 demonstrate clearly the 8 minute turn-out area of Falkirk station under the base case (standard road speeds) scenario. Falkirk station is labelled and each black dot shows a junction reachable within 8 minutes.

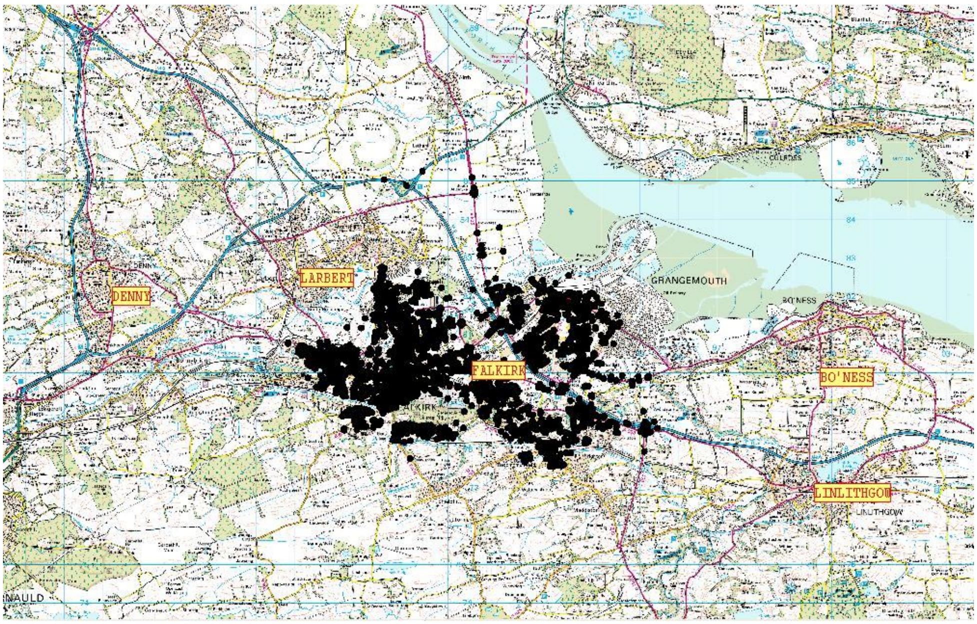

Figure 3 - Falkirk Station 8 minute turn-out area under standard road speeds

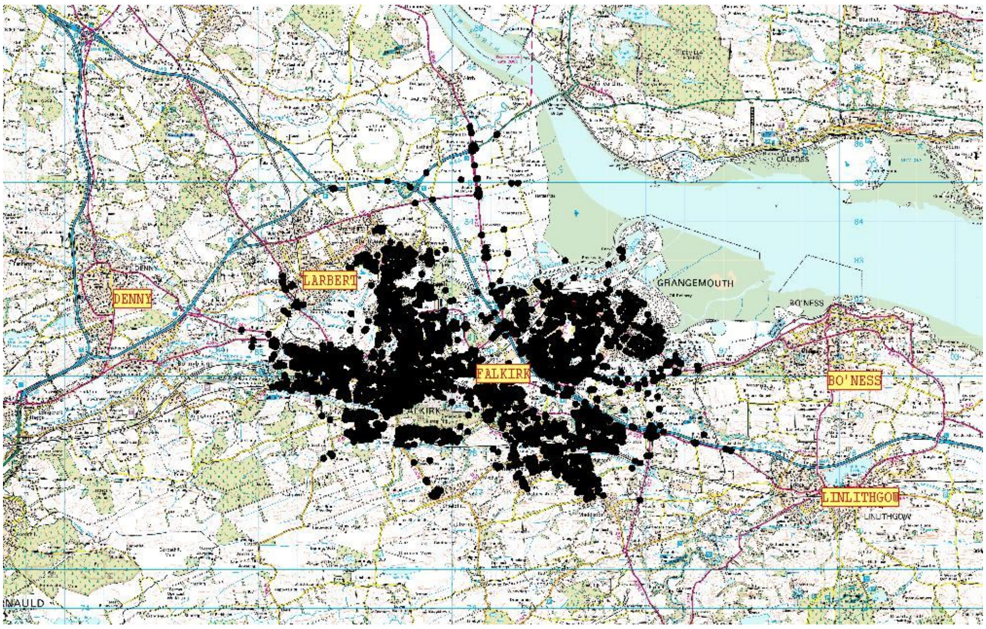

Figure 4 - Falkirk Station 8 minute turn-out area under proposed siren – 30% increase in road speed

Further comparison of the two images and distance performance results, presents a noticeable extension in turn-out area which is visible across the region. In particular, the proposed system achieved far greater penetration into the Larbert and Grangemouth areas, along with further reach along motorways (blue roads) in the North and South East of the map. This shows that by emergency vehicles travelling only 30% faster on average, considerably more ground can be covered than currently possible. Given that the speed of emergency response is crucial to clinical outcomes in cases such as serious blood loss and airway obstruction [3], this extension in reach within the crucial 8 minute timeframe; now standard in the UK and USA, could prevent life-threatening situations in outlying areas of the region.

Effectively the combination of both systems could result in an increase in average speed of up to 30% for emergency vehicles. In the simulation FSEC environment the predicted impact of this increase on the emergency vehicles' speed results in the decrease of one fatality every 1.4 years in road traffic collisions, 4.3 years in dwelling fires and 9.8 years in building fires respectively. The damages will also be decreased dramatically by a yearly saving of £477,754.7. The aforementioned results are focused in the area of the town of Falkirk and the area of operations in an array of 8 minutes from the centre of Falkirk (35.000 population). The potential impact though of the proposed system in the major cities of Glasgow and Edinburgh and in extend in the whole Scottish region would offer a significant fatality decrease of approximately 148 fatalities and reduced damages and operational costs up to £70 Million per annum. For the purpose of examining the further trends of these scenarios, a full series of models were run to show increases in speed from +5% through to 25% in 5% increments, in addition to +30% to +50% in 10% increments as illustrated in the Figures 5, 6, 7 and 8.

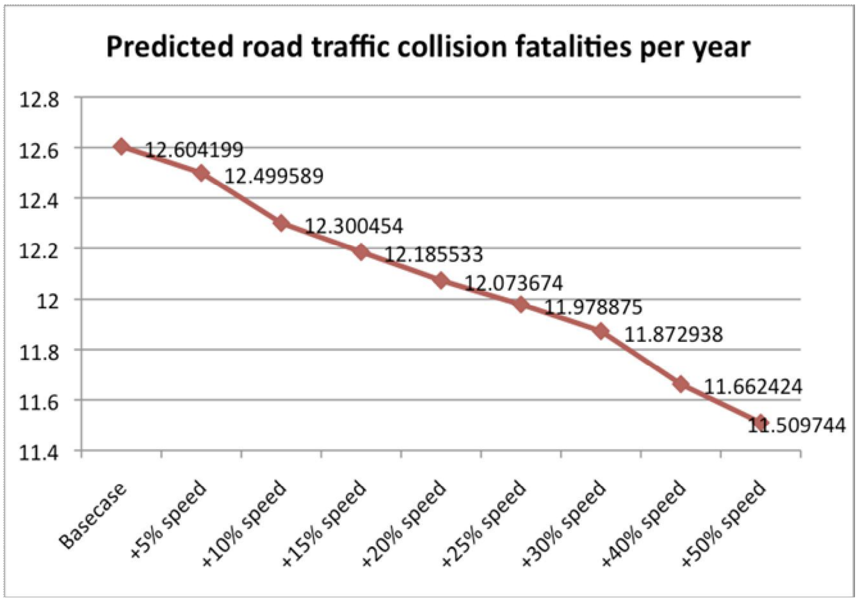

Figure5 - FSEC Predicted road traffic collision fatalities per year

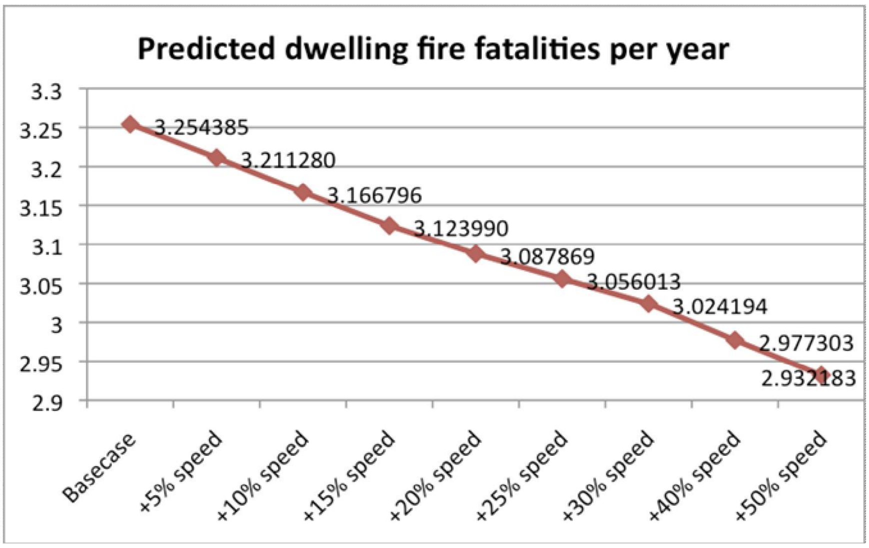

Figure6 - FSEC Predicted dwelling fire fatalities per year

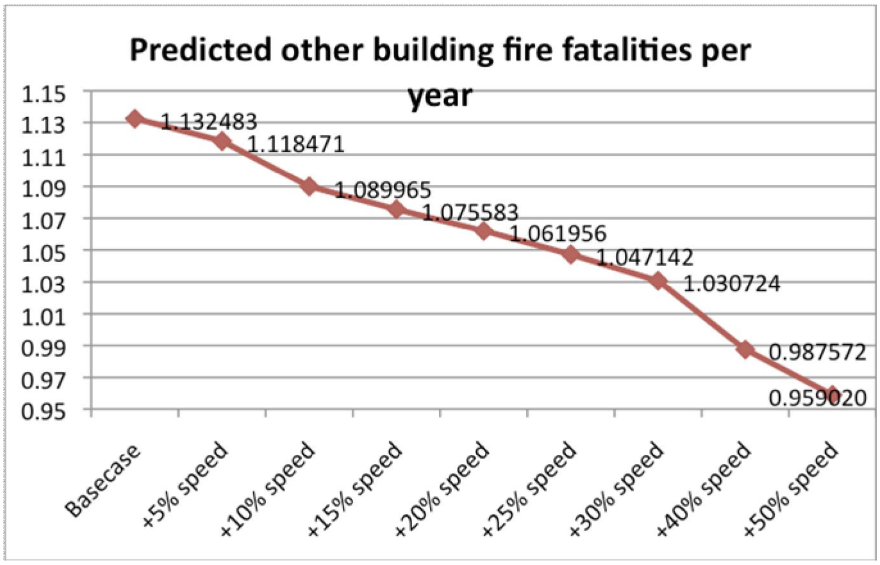

Figure7 - FSEC predicted yearly other building fatalities under base-case and increased road speed scenarios

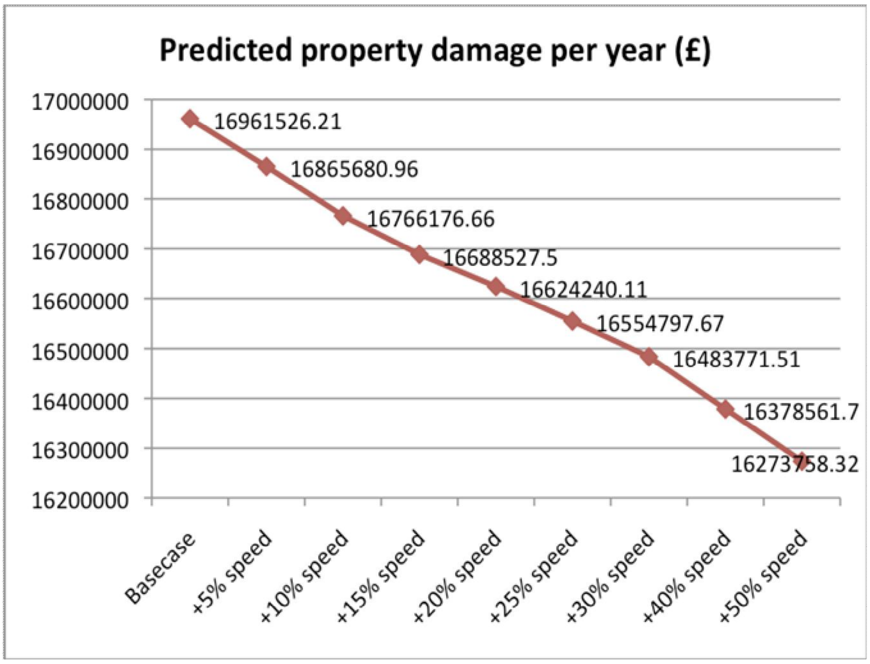

Figure 8- FSEC predicted yearly property damage figures under base-case and improved road speed scenarios.

It is evident that in all the simulation predictive models the graphs present a linear decrease in yearly fatalities, and damages as emergency vehicle road speeds are increased. As per the quantitative research process, increased speeds of 5-25% were modelled in +5% increments. To demonstrate the trend beyond this range, 30-50% increases in average road speed were also included in +10% increments.

CONCLUSIONS

This paper presented the preliminary examination of the inherent issues in the localisation of emergency vehicle audible warning systems. The study has employed quantitative research of emergency vehicle drivers in combination with the findings of previous road tests by the West Yorkshire and London Ambulance Services, in order to calculate the impact on the speed of the emergency vehicles. Evidently the emergency vehicles could achieve an increase in average road speed of up to 30% through use of the proposed prototype siren system. In addition to providing evidence to these initial results, the quantitative research carried out, collected the subjective feedback of emergency services personnel which informed our development and customisation process of the proposed auditory system. Our tentative plan of future work entails the development of further user-trials on a driving simulator which will reproduce the sound propagation in a three-dimensional manner. In turn we aim to enhance the suggested auditory cues by the use of a prototype Head-Up Display system, [12] that has already been designed for early collision avoidance warning.

REFERENCES

1. Saunders G. and Gough A., (2003), Emergency Ambulances on the Public Highway Linked with Inconvenience and Potential Danger to Road Users, Emergency Medical Journal, Vol 20, pp 277-280.
2. Blauert J., (1983), Spatial Hearing: The Psychophysics of the Human Sound Localisation, MIT Press, Cambridge, Massachusetts.Department of Transport UK, (2008), 2008 Road Traffic Collision Statistics.
3. Withington, D. J. & Paterson, S. E., (1998), Safer Sirens, *Fire engineers journal*, Vol. 48, pp. 6-10.
4. Wightman, F. L. & Kistler, D. J., (1993), Sound localisation. Human psychophysics. Springer-Verlag, New York. pp. 155-192.
5. Wenzel, E. M., Arruda, M., Kistler, D. J. & Wightman, F. L., 1993. Localisation using non-individualised head-related transfer functions, *Journal of the acoustic society of America*, Vol. 94, pp. 111-123.
6. Withington, D. J., (1996), The quest for better ambulance sirens, *Ambulance UK*, Vol. 11, pp. 20-21.
7. Ho, C. & Spence, C., (2005), Assessing the effectiveness of various auditory cues in capturing a drivers visual attention, Journal of experimental psychology: Applied, Vol. 11, pp. 157-174.
8. Lenné, M. G., Triggs, T. J., Mulvihill, C. M., Regan, M. A., Corben, B. F., (2008), Detection of emergency vehicles: Driver response to advance warning in a driving simulator, *Human factors*, Vol. 50, pp. 135-144.
9. Llaneras, R. E., Green, C. A., Kiefer, R. J., Chundrlik, W. J., Atlan, O. D. & Singer, J. P., (2005), Design and evaluation of a prototype rear obstacle detection and driver warning system. *Human factors*, Vol. 47, pp. 199-215.
10. Dian-liang Xiao; Yu-jia Tian, (2009), Reliability of Emergency Rescue System on Highway, in Proceedings of: Second International Conference on Intelligent Computation Technology and Automation, (ICICTA '09), Changsha, Hunan, China Vol 2, pp 564 – 567.
11. Sherratt, R. S., (2000), Results of a DSP based adaptive cancellation filter system for the chirp, pulsar and localiser sirens, *IEEE Nordic Signal Processing Symposium (NORSIG2000), KolmArden*, June, pp. 235-238.
12. Charissis V., Vlachos G., Chan W. and Arafat S., (2010), Early Notification Warning System for Prototype Head-Up Display: Development and Evaluation of Traffic Congestion and Sharp Turn Warnings, in Proceedings of the Society of Automotive Engineers (SAE) World Congress 2010, 12-15 April, Detroit, Michigan, USA.

ACKNOWLEDGMENTS

The authors would like to thank the ex-Chief Fire Officer Steven Torrie and the personnel at Central Scotland Fire and Rescue Service for providing this study with essential information for the development and testing of the proposed system. We would like also to extend our gratitude to Station Manager Steven Buchanan for his insight and invaluable assistance in using the FSEC system and provision of information.