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LIFE Project: Implementing a modelling framework for emergency vehicles advanced priority strategies

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Abstract

Given the aging demographics and rapid urbanisation, cities need to be equipped to respond to emergency (eg. 999 calls) more quickly. By 2050, over 25% of the UK's population will be over 65. This has implications on the overall health services as well as the NHS Trust to cope with anticipated rise in ambulance call outs amidst worsening urban congestion. Ambulance services are required to reach 75% of emergency calls within 8 minutes. For this reason, there is a growing need to develop new and innovative applications for an even more intelligent use of the existing transport system that will support in real-time emergency vehicles to reach life threatening emergency cases quicker.
this paper will discuss the methodology and the preliminary results of the modelling framework implementation of a "Life First Emergency Traffic Control" or "LiFE" system, a ITS implementation seeking to identify the best solution to reduce the time to respond to emergency calls, whilst operating a resilient service with a cost and fuel-efficient fleet. Results of the application of a microsimulation model to replicate the behaviour of ambulances in urban area and how different reactions of general traffic can impact on the travel time of an ambulance are presented. The proposed microsimulation modelling framework has been developed with the final aim to understand and evaluate the impacts and the best scenarios to improve ambulance (or any Emergency vehicle) response time and gains in cost-saving, whilst assessing mitigation strategies to reduce other impacts such as residual congestion.
The work is part of an Innovate UK collaborative funded project, namely Life First Emergency Traffic Control (LiFE) with the aim to develop an innovative application for an intelligent transport system that operates in real-time to enable ambulances to reach life threatening emergency cases quicker by integrating ambulance route finder applications with traffic management systems.

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1. Introduction

A recurrent problem that affect emergency vehicles is reaching their destination on time, according to the different target set by law. This is caused by increasing traffic and congestion in modern cities. Especially in urban areas, the mix of road users and the presence of traffic lights, makes driving at a higher speed without causing any harm to anybody even more difficult for the emergency vehicle drivers itself. Currently, the issues of ambulance services to meet the Government's target of responding to 75% of life threatening calls within 8 minutes (Guardian, 2015), is becoming more complex year on year. Although critical emergency calls are time-sensitive (i.e. heart attacks, strokes etc.), the national audit office (NAO) reported a performance of 67.2% for 2016 which is 7.8% below the government target, proving the situation is becoming increasingly critical. An international best practice review suggested that the response time should be approx. 5 min. to increase the survival rate by 12% (NHS, 2014).
Aside from operational issues, ambulance services currently face (e.g. 10% of 999 calls are genuinely life-threatening conditions, while categorising 40% of calls, resulting in dispatched vehicles before having determined the exact nature of the problem), the LiFE project approaches the poor ambulance response performance from a transport and city level point of view. This is further exacerbated that ambulances in the UK are not legally allowed to travel 10mph above the speed limit, as this could potentially cause more accidents. On average, 4 ambulances are involved in crashes each day resulting in a total cost for compensation and repair bills of £300K every month (Casey et al., 2011).
In Plano, Texas, the Emergency Vehicle Pre-emption (EVP) system has dramatically reduced the number of emergency vehicle crashes from an average of 2.3 intersection crashes per year to less than one intersection crash every five years (US DOT, 2006), whilst in Fairfax, Virginia, the EVP system has been shown to save anywhere from a few seconds to a few minutes. Ambulance drivers cited savings of 30-45 seconds at a single intersection (US DOT, 2006).
Shah et al. (2013) in their empirical analysis, demonstrated the effectiveness of their Road Traffic Accident Management approach by modelling an inter-urban area of Yorkshire (UK) and by considering real data in terms of distribution of emergency vehicles, speed and probability of accidents. More recent applications to identify best ambulance deployment strategies using advanced modelling techniques have been used by Naoum-Sawaya & Elhedhli (2013); Bélanger et al. (2015) and Galpin (2016), however traffic microsimulation modelling have not been used so far.
England has 10 Ambulance Service NHS Trusts all of which have similar needs and same pressure to meet the Government's 75% target (NHS, 2015). Of 1.1m emergency calls last year, approx. 68% require emergency transport (NWAS, 2015). Across the UK, the Diagnostic and Ambulance Services Market (D&AS) has an annual growth of 2.7% (2010-2015) with a revenue of £6bn, driven by UK's ageing population. Total demand of the £800m a year UK ambulance service industry is expected to grow significantly in the next 10 years demonstrated by the double digit growth in spending on private ambulances by the NHS over the past two years (Plimsoll, 2013).
Crashes are a significant problem for ambulances and all emergency vehicles, in the US it was found that 25% of all accidents involving emergency vehicles occurred at signalised intersections especially where line of sight was blocked by buildings or vegetation (Viriyasitavat & Tonguz, 2012). In the UK cost for compensation and repair bills of ambulance crashes totals £300K every month (EveningStandard, 2008).
Also, the bus priority applications that can be seen in many cities worldwide use pre-emption systems to save time especially when they are beyond schedule. (CORDIS, 2016). An application that is a precursor of the LiFE concept is the EViEWS system, deployed in Texas since 2014. Through GPS signals transmissions and a wireless communication, speed and position data of emergency vehicles are sent to traffic lights, that are then turned green to provide prioritisation. (Lloyd, 2014). The latter however is not the first emergency vehicles pre-emption technology used so far. Global Traffic Technologies (GTT) introduced the Opticom system is 1968, which again makes use of GPS signals and wireless communication, in combination with the siren activation, to trigger the green phase according to the ETA to the signal (ITS Int, 2015).
The pre-emption technique has proved through the different on site applications to reduce journey times, however also traffic modelling studies demonstrate that it easies the movement of emergency vehicles in urban areas (Sharma, et al., 2013). Algorithm based approaches have been carried out to determine whether enabling priority at intersections would actually reduce travel times for emergency vehicles and it has been found out that since the green wave allows the emergency vehicles to go faster, they do not experience slowdowns at the intersection and additionally crashes are prevented (Viriyasitavat & Tonguz, 2012). Not many are the experiments carried out so far using traffic microsimulation software. An example though is represented by (Wang et al., 2013) where a Vissim model has been used to validate a mathematical model that estimates travel times for vehicles under pre-emption control. The approach used here sees the deployment of an emergency lane that is activated at random times, from where vehicles move to the outside lane to let the EV through. Other studies focused on the emergency vehicles routing decisions, where assignment models that take into account the demand and travel costs variability on the network have been used to develop a travel time function able to forecast emergency vehicles routing.

(Musolino et al., 2013). A recent study by (Zhang et al., 2016) who developed a utility model to evaluate the performance and reliability of emergency vehicle (EV) travel time that draws very little attention previously. The application of this model in our study can demonstrate the impact and importance of EV response time.

Research gaps: There is a clear need for the traffic systems of the city to support faster response times through prioritisation. In the US emergency vehicle pre-emption (EVP) at signalled crossings has been taken up widely across the country with improved ambulance journey times.
This is not the first time a concept like this takes place: other systems, such as the European Compass 4D, looked at prioritising vehicles at traffic lights through V2I/I2V communication, as well as warning drivers of possible road hazards (V2V communication). However, the system that has seen only a trial version of it, is not deployed yet and even though it has been proved to be efficient in terms of reducing emissions at intersections and journey times. For these reasons a test with emergency vehicles should be run and is the focus of this paper, as well as a real trial is the aim of the LiFE project in the coming months.
Moreover, current and traditional traffic microsimulation modelling tools, have been used default functions which are not designed to model an ambulance and the behaviour of traffic when an ambulance is going through it.
Unlike EVP, the LiFE project idea goes beyond traffic lights responding to an ambulance's approach but integrates route finder applications with traffic management systems. The proposed application is developed to be integrated with existing systems in ambulance vehicles and therefore complements current solutions. Also, the LiFE system has been designed using ethnographic research into ambulance driver behaviour to ensure LiFE is fit-for-purpose for the end-user with feedback loop mechanisms throughout the project.
As the modelling activities within the project have begun recently, this paper will focus mainly on the initial results of the implementation of the microsimulation modelling methodology with a validation exercise for the base case and in the steps to model the improvements of the response time of ambulance services through a predefined corridor.

Main Aims and objectives: To overcome the above identified issues, the LiFE project aims at reducing the travel time of emergency vehicles in a safely manner, namely prioritising them at traffic lights or rerouting them where the combination of traffic and road conditions would allow a shorter drive.
Within this paper several objectives will be achieved:

- For the first time a traffic microsimulation model will be used to reproduce realistic traffic behaviour in presence of ambulance;
- The modelling framework and API module settings used within the microsimulation tool will be presented;
- A real study area will be reproduced using real-world ambulance data, and
- Preliminary validation and transferability results for two selected corridors will be presented alongside the benefit of implementing the new modelling software.

2. The proposed framework

Key and unique aspect of the work undertaken in this paper is the process that has allowed the microsimulation tool to be adjusted in order to enable an existing microsimulation model to replicate realistically traffic conditions when an ambulance on blue light (highest emergency code) is going throughout a representative urban corridor. The real-world datasets used to calibrate and validate the microsimulation tool and support the modelling framework have been made available by the North West Ambulance Service (NWAS) and Siemens (SCOOT data) based in Liverpool, UK.

2.1. The microsimulation model

The traffic microsimulation software used to analyse the LiFE system is the German Vissim 8.12 commercially available through PTV Group. The reason why it has been chosen among the other commercial software available is the more realistic behaviour of the vehicles, with the possibility for them to overtake both in the same lane and in the opposite lane. Vehicles that have enough lateral space (defined by the user) and a desired speed higher than those in front, may overtake in the same lane, as well as in the opposite lane if not upcoming traffic is detected.
The main purpose of the application of a microsimulation traffic model within this work was to analyse trips and variation of travel time of emergency vehicles (EVs), however microsimulation was used also to reproduce and monitor the reactions of drivers in urban areas that traditionally react in different ways in presence of ambulance, as function of the road layout and speed, therefore the feature required was from one hand the ability for the EV to overtake standard traffic, but also for the standard traffic to implement manoeuvres that are not by default possible to implement in a traditional microsimulation software.

In fact, by default the overtaking feature in Vissim allows all the classes of vehicles defined by the user to be overtaken by vehicles with higher desired speed, but vehicles of same defined classes may overtake as well depending on the speed they desire to travel at, as mentioned earlier. In other words, it was not possible for EVs only to overtake all the other vehicles on the road network by default.

Hence, in order to also achieve a realistic behaviour of the traffic in presence of an EV, an external driver model able to control vehicles' behaviour on the Vissim network has been identified as the only solution to model realistically ambulances and traffic affected by EVs.

2.2. The external driver model

By designing and implementing an external driver model, the intention is to override most of the vehicles' behaviour. In this way, Vissim vehicles do not follow anymore the behaviour embedded in the software, but instead the instructions the external model send to them in certain circumstances (approaching traffic lights, EVs behind or in front, etc.).

Emergency services are mostly operating in critical conditions; thus, an efficient journey planning is vital in improving time-response to a distress call. Modelling and analysing travel time in different traffic conditions and road types could prove very helpful in decision making and better allocation of existing resources. Vissim is an established software package in microscopic traffic simulation, capable of providing a realistic model of road users while allowing the flexibility to inject external models for vehicle behaviour. VISSIM has an External Driver Model for as DLL interface which provides the option to replace the default driving model with a user defined one as long as the choice is activated for that particular vehicle type. The possibility of incorporating the external driver model into the software has made it feasible to reproduce realistic conditions in the traffic simulator, where standard vehicles are made aware of EVs approaching and react accordingly.

2.3. General Implementation Guidelines

The DLL is implemented in C++ and has to follow VISSIM structural guidelines.

The DriverModel.h is a pre-defined header file containing all the definitions necessary during the simulation, the DriverModel.cpp represents the main source file which must implement three functions: DriverModelSetValue, DriverModelGetValue and DriverModelExecuteCommand.

During the simulation run, VISSIM calls the DLL every time step for each vehicle type actively controlled by the external model in this order: SET, GET and EXECUTE COMMAND. Every Set, ExecuteCommand and Get calls are dealing with data embedded within the current vehicle object. In parallel, there is a hash map which holds an array of ‘Vehicle’ objects and uses as a key the vehicle unique identification number. The map contains all the vehicles active in the simulation.

If a vehicle knows its neighbour’s id it can check on the map the type of that particular id alongside other vehicle specific parameters.

		2 lanes left	1 lane left	current lane	1 lane right	2 lanes right
		0	1	2	3	4
2 ahead	0	id (0,0)	id (0,1)	id (0,2)	id (0,3)	id (0,4)
1 ahead	1	id (1,0)	id (1,1)	id (1,2)	id (1,3)	id (1,4)
				Current Vehicle		
1 behind	2	id (2,0)	id (2,1)	id (2,2)	id (2,3)	id (2,4)
2 behind	3	id (3,0)	id (3,1)	id (3,2)	id (3,3)	id (3,4)

Fig. 1 Matrix for the neighbours vehicles' ids

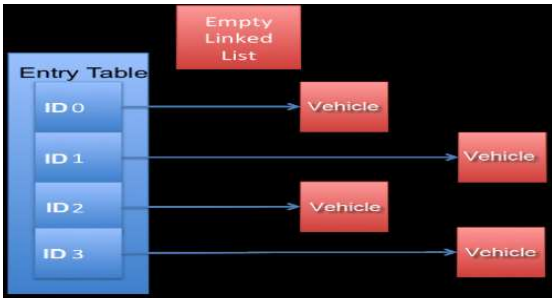


Fig. 2 Vehicle Hash Map

2.4. Specifications

In order to implement the behaviour of ambulances and the affected vehicles, a certain degree of traffic disturbance was implemented according to previous calibration exercise by Galatioto et al. (2017).

The first limitation experienced was the fact that at any time a vehicle could interrogate the ID of the neighbours but not their types, thus a car would be unware of who is the ambulance in the proximity.

The problem was solved by defining a 'Vehicle' structure holding all the necessary parameters updated during 'Set' calls and a matrix with the neighbours' unique identification numbers as seen in the Figure 1.
The ambulance has the ability to identify gaps in the upcoming traffic, to evaluate if the vehicle ahead is offset lane by checking the lane lateral position and accelerate past and to ignore the red traffic warnings.
The scenario when the non-emergency behaviour vehicle has no ambulance behind in the current lane is described in the Figure 3. Depending on number of lanes and speed of the vehicle in front (within awareness distance) of the ambulance the options are to change lane or decelerate and give the way, these depend on the route of the ambulance and if it changes lane or not, or if there is congestion with low or zero speed of the vehicle in front.

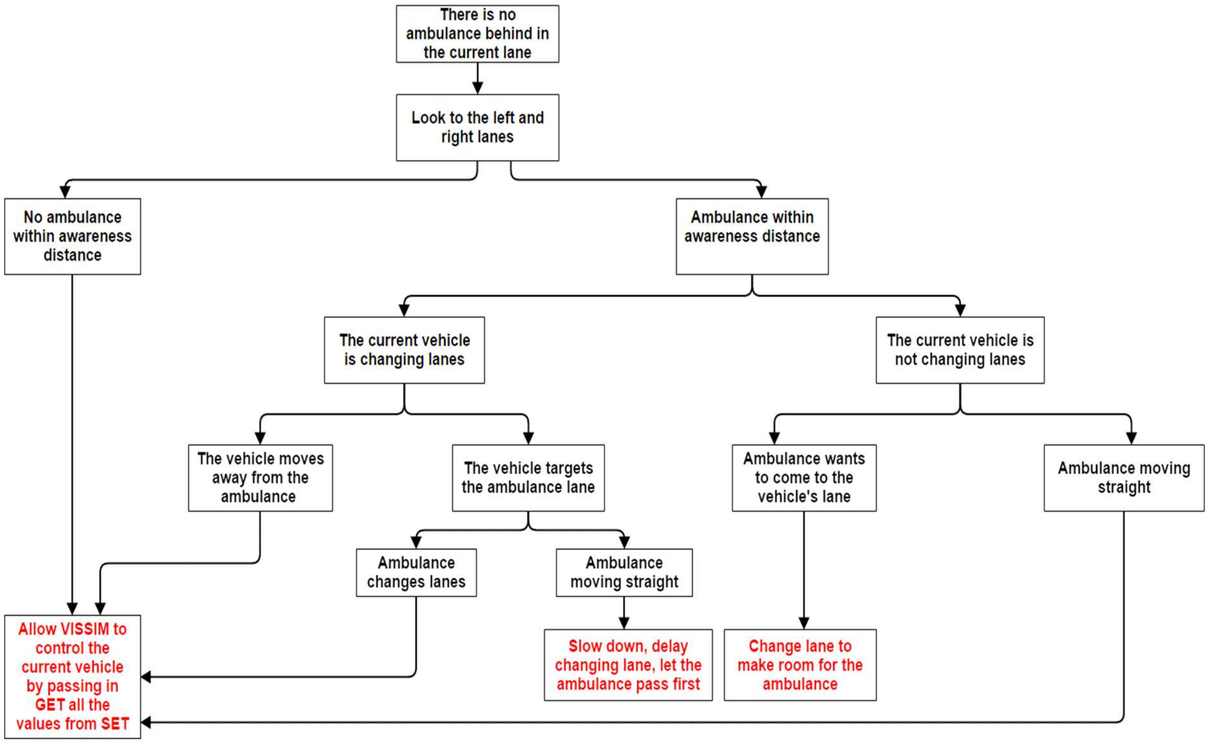


Fig. 3 No ambulance behind in the non-emergency's vehicle current lane

The scenario when the ambulance is two cars behind is described in Figure 4, while the scenario when the ambulance is one car behind is described in Figure 5.

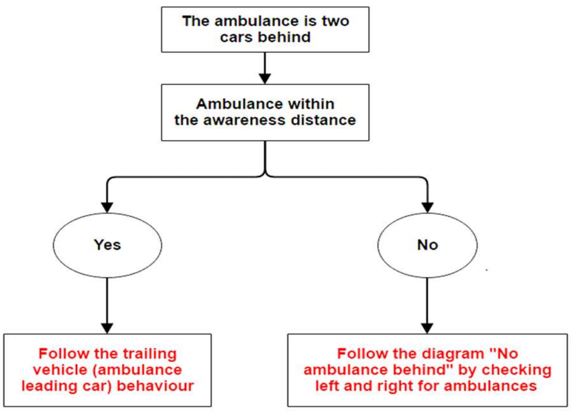


Fig. 4 Ambulance two cars behind

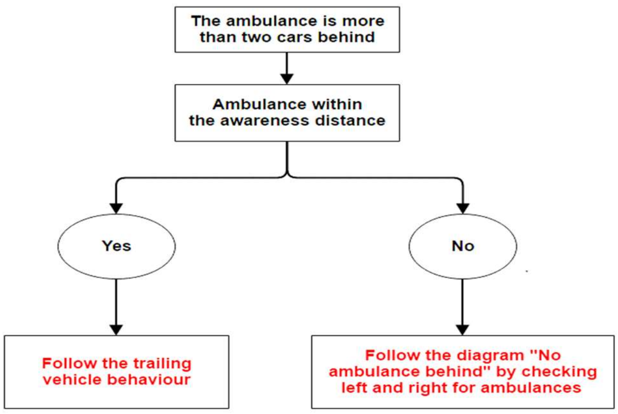


Fig. 5 The ambulance is one car behind in the current lane

The scenario when the ambulance is more than two cars behind in the current lane is described in the Figure 6.

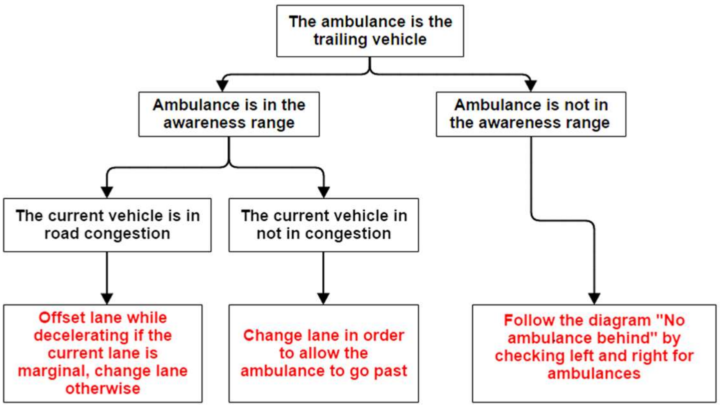


Fig. 6 The Ambulance is more than two cars behind in the current lane

3. Application of the framework and results

3.1. The study area

For the testing and calibration of the external driver model a urban network in Milton Keynes (Study area 1, Figure 7), previously calibrated and validated for a base case scenario in a different project, extended on an area of 3.5km2 in the vicinity of the Transport Systems Catapult premises, has been used. While to demonstrate the transferability of the framework developed, a second network in Liverpool (Study area 2, Figure 7), was chosen and full calibration, validation of the network and framework were performed.

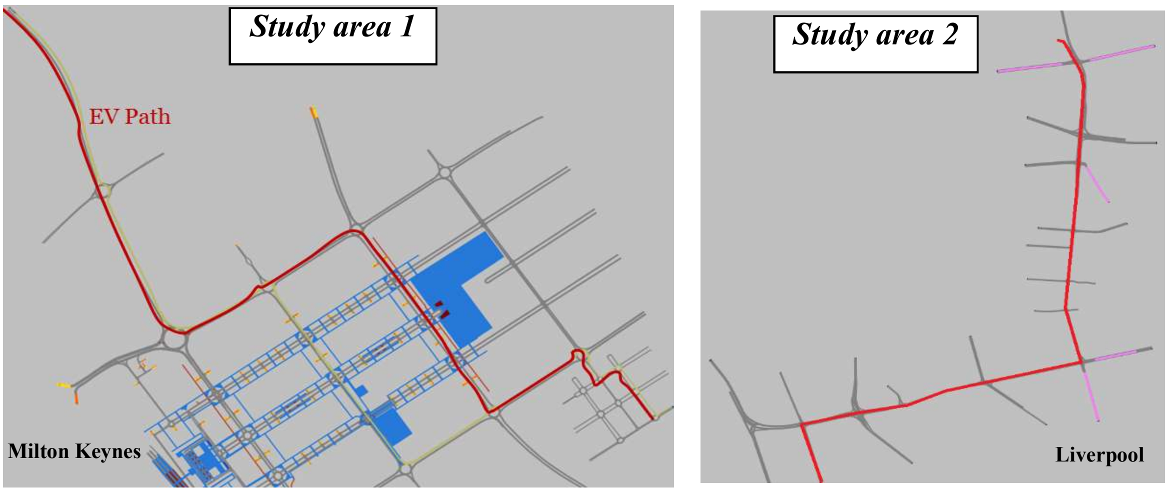


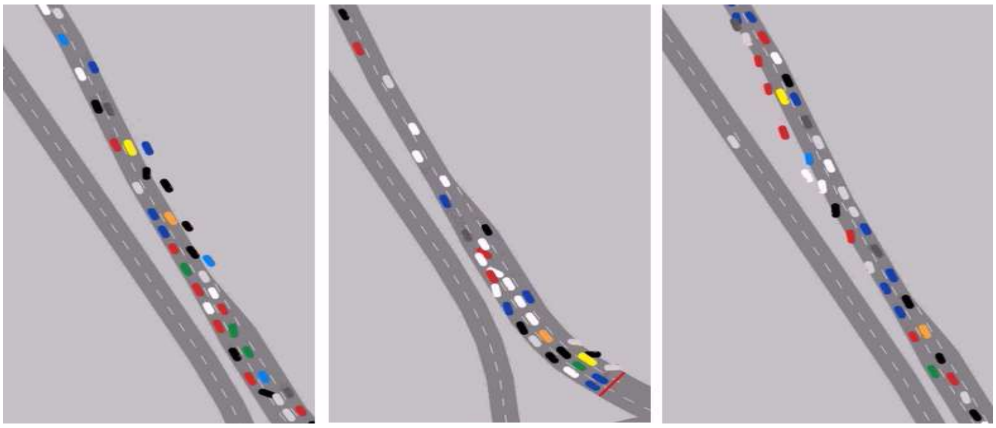
Fig. 7 Traffic network layouts for the two study areas (EV journey in red)

Since red calls should arrive at destination within 8 minutes from the time the call has been taken, the ambulance journey (in red) was chosen of a length of approximately 4.5 and 3.5 km respectively for the two study areas, which in normal traffic or overnight take up to 6 minutes, but during peak hours can easily take over 10 minutes. The time modelled for this exercise was between 7:30am and 10:00am for both areas, with 30 minutes warm up period.

3.2. The calibration of the external driver model

In order to calibrate the newly developed external driver model, several scenarios of ambulance going through traffic both on links and junctions of the study area 1 have been replicated and realistic behaviour have been possible to replicate in the microsimulation model (Figure 8).

Fig. 8



Screenshots of three different modelling scenarios of ambulance (long yellow vehicle), using the novel external driver model

To stress test the external model, higher level of flows were also considered during the calibration of the first study area. For each scenario result, 10 different unique simulations (using different seeds) were carried out. In Figure 9 are reported the results of running the simulation with 3 to 5 ambulances inserted in the network every 10 minutes, this was done in accordance to previous method adopted by the authors in Galatioto et al. (2017) to limit multiple ambulances to proceed on the same corridor at the same time, even though that is a real possibility.

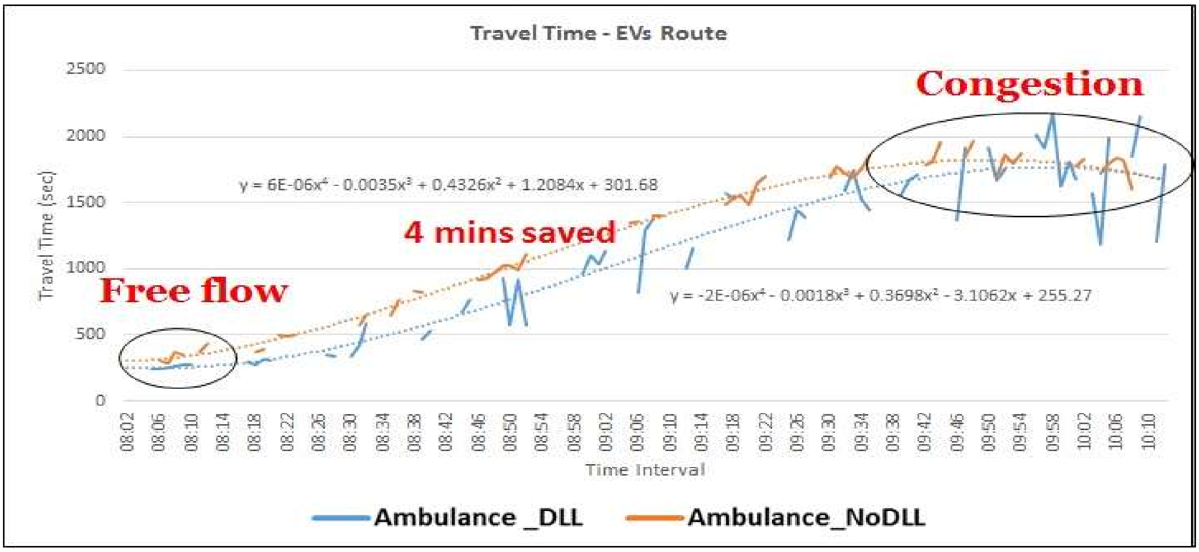


Fig. 9 Travel time of Ambulances (EVs) through the simulation period with and without implementation of the external model (DLL)

It can be observed that the external model produces a real benefit of around 4 minutes for traffic level which can be classified as busy, while for free flow, as expected, the time saving is minimal (mainly associated with the ability of EVs to go through red light at signalised junctions). Similarly, for highly congested period EVs cannot take advantage of either the external model, since surrounding vehicles are not able to move easily, and the ability to go through red light.

This, as highlighted in Figure 10, which refers to results from the same network, but implementing reduced flow levels, provides a useful perspective on when both temporally and geographically a LiFE system application will make a real difference in enabling the ambulance to reduce the travel time to meet the Travel Time (TT) target.

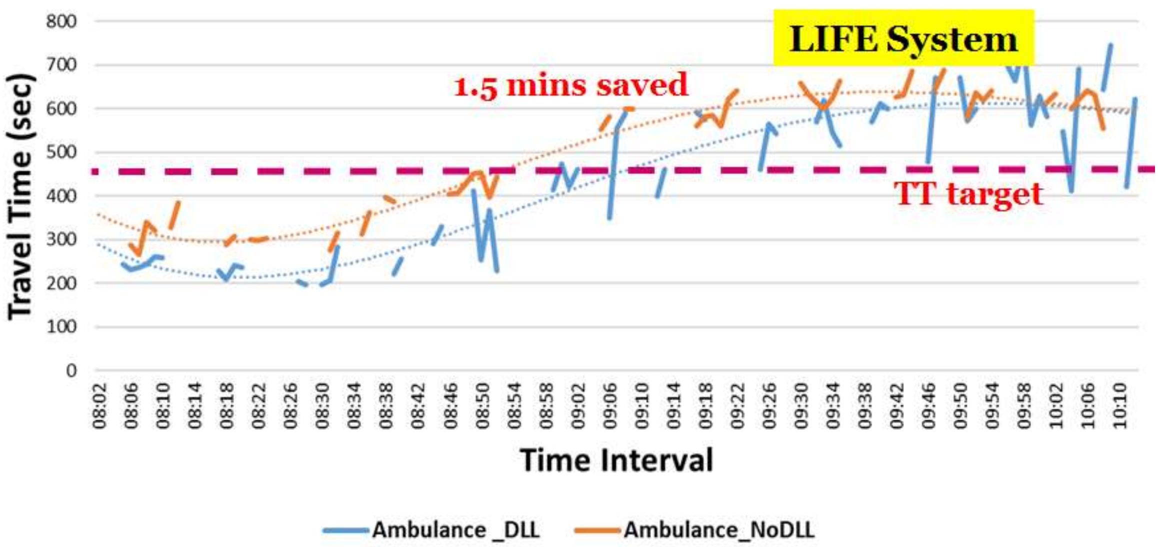


Fig. 10 Simulation results of ambulance trip travel time for same traffic network layout but with less congested conditions.

3.3. Transferability of the modelling framework and results

To test the transferability of the modelling framework and to validate the external driver model, the study area 2 in Liverpool was used. For the calibration and validation of the traffic network, data from SIEMENS UTMC in the form of ASTRID (traffic volumes, delay and stops at 15 minutes resolution) were used and in Fig. 11 the results

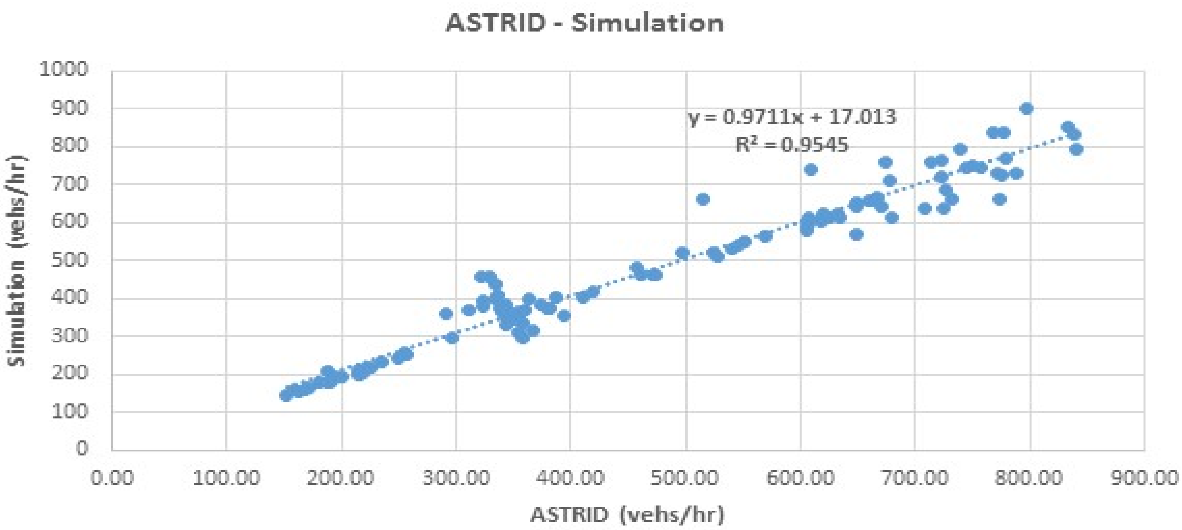


Fig. 11 Validation results of the study area 2

of the comparison of modelled and measured flow are presented. The overall validation gave a result of 95% of detectors with GEH below 5. For the validation of the external driver model real-world travel time data in the form of AVL were provided by the North West Ambulance Service (NWAS). Several Ambulance and Rapid Response Vehicle data were collected for the peak hour period and used to replicate the scenario in the microsimulator using the calibrated external driver model. In Figure 12 are presented the results of the validation (using 10 simulation runs per scenario), for both Ambulances and Rapid Response Vehicles (RRV). The results show that for the single junction to junction travel time there is a variability but is within the statistical error (95% confidence level), while for the overall trip J1 to J5 the accuracy of the model is even better for both type of emergency vehicles.

Fig 12 Validation of the modelled vs measured travel time of Emergency Vehicles in study area 2

To verify that the model is capable of replicating a real traffic network, travel times in the model have also been measured for different traffic conditions. A particular focus has been given to emergency vehicles travelling in presence of congested levels of traffic flows. In order to obtain a quite congested network, the original flows have been doubled, and the scenario so set up constituted the base case of such modelling exercise. Starting from this scenario, on both the horizontal and vertical corridors of Study Area 2 (figure 7) the flows have then been increased of 10, 20, and 30%, changing the turning percentages of the Vehicle routes in Vissim so that the increase of traffic would happen only on the main corridors and not on the side roads. Travel times have been measured for both standard and emergency vehicles, again averaging the outcomes of 10 simulation runs for each scenario. The results (figure 13) show that in 35% of the cases emergency vehicles' travel time is above the target. Being the national statistic figure 30%, the model is therefore well replicating real traffic conditions.

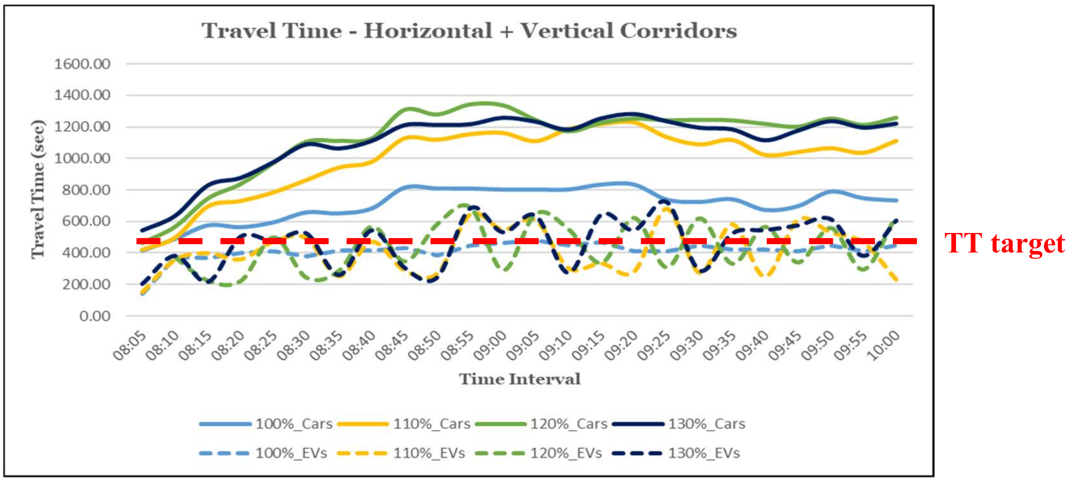


Fig.13 Travel Times of standard and emergency vehicles in scenarios with different levels of traffic congestion

4. Discussion and Conclusions

This paper presented the development and calibration of a modelling framework to enable a commercial microsimulation model to accurately replicate ambulance (or generically Emergency Vehicle) trips across a transport network and through two case studies the preliminary application and validation results of the novel proposed driver model.

The external driver model has been designed and developed to work independently from any microsimulation network configuration and geometry, this is because it overrides the vehicle behaviour according to the dynamics on the surrounding environment (eg. speed limits, speed of the surrounding vehicles, position of the EV in respect to each individual vehicle) and this has been successfully proven by transferring the model between two different network areas.

The results obtained show that the application of the new driver model developed provides realistic travel time that in real-world condition an ambulance going through an urban area and for different traffic levels is expected to achieve, however the model results also highlight that with congested traffic levels, ambulance travel time cannot be currently reduced beyond a certain limit, which unfortunately is not enough to achieve the set target of 8 minutes. This reinforce the need to implement a new ITS system which is currently under development as part of the LiFE project. Transferability and validation of the external model and framework has been proven, this provides a solid basis to test and assess the future LiFE multi-link based pre-emption strategy using the new external driver model.

5. Future Work

This paper presented the results of the application and transferability of the external driver model developed in Galatioto et al. (2017) to enable a commercial microsimulation model to replicate ambulance trip accurately and also to model the behaviour of the traffic when an emergency vehicle is going through it. The successful transferability of the approach has been demonstrated in the Liverpool network.
Short-term: the next step for the LiFE modelling group is currently developing and testing new scenarios where different intelligent priority scenarios, using the coordinator developed algorithm to calculate in real-time the ambulance TT, will be assessed within the validated traffic network, this to provide to the Coordinator (RedNinja) enough scientific evidence base of travel time saving compared to the current situation and existing alternative.
Long-term: beyond the scope of the LIFE project, the Transport Systems Catapult want to follow the development of wider traffic control strategies, including rerouting options for the ambulance, taking into account of real-time traffic condition and congestion on the network.

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