IMPACT OF SELF-DRIVING AND CONNECTED VEHICLES ON EMERGENCY RESPONSE: THE CASE OF THE USA AND IMPLICATIONS FOR ITALY

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ABSTRACT

Studies have shown that mortality rates are directly correlated with emergency response times. Cardiac arrest events, trauma, and stroke are among the most time dependent. Response time, in turn, is greatly affected by traffic and procedures currently required at intersections. New technology promises more efficient flow at these locations. In particular, connected and autonomous vehicles can contribute to reductions in response times and resulting reductions in mortality. The purpose of this paper is to provide a framework and a tool for analysis of these improvements and reductions. Application of the framework for Lexington, Kentucky, USA indicate a potential three-minute decrease in response time with subsequent reduction in fatalities. Extrapolated to the USA, the savings are potentially quite significant. The paper goes on to speculate on implications for Italy.

Keywords: connected and autonomous vehicles, emergency response times, virtual emergency lanes.

1 INTRODUCTION

Connected and autonomous vehicles (CAV) have been regarded as the best response for eliminating human error and saving lives on roadways. Although the technology includes a safety benefit to decreasing roadway fatalities, what other safety benefits can the technology provide? According to the Center for Disease Control and Prevention (CDC), the top causes of death in the United States for 2016 include heart disease, cancer, accidents, chronic lower respiratory diseases, stroke, Alzheimer's disease, diabetes, influenza, nephritis, and intentional self-harm [1]. The types of deaths are correlated with response times, as some are time-sensitive and require immediate medical attention. Pre-hospital fatalities make up 16% of all fatalities in the United States [2]. Removing the immediate fatalities from impacts, most pre-hospital fatalities occur from longer emergency response times. Emergency dispatchers today are equipped with live location data of the emergency units, which allows for the closest unit to respond to a call [3]. Even though dispatching the closest unit available will save time in responding, human drivers and EMS response procedures still slow the EMS unit down, whether for an inattentive driver or an intersection ill-prepared for an emergency vehicle approach. Human interference to emergency responders poses the question, how can CAV technology eliminate human error and decrease emergency response times, increasing the survival rates of time-sensitive patients in urban areas?

As of 2018, the average emergency response time is over nine minutes [4]. Faster response times are proven to provide higher survival rates [5]. Time-dependent emergencies make up 25% of all medical calls across the nation, including 9.7% being the most time-sensitive call, cardiac arrests [6]. Cardiac arrest mortality rates increase 7% to 10% for every untreated minute [7]. Other time sensitive cases have a 1% to 2% increase in mortality rate, but the largest spikes in mortality rate occurs at the five-minute mark and the eight-minute mark [8], [9]. By reducing average emergency response times to under eight minutes, cardiac arrest

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mortality rates would be reduced by around 8.5% and other time-sensitive cases would be reduced by 1.5%.

Vehicle-to-infrastructure (V2I) technology can enhance preemption at signalized intersections. Pre-routing of the emergency vehicle could enable signals to have more accurate preemption, reducing or eliminating stops at signalized intersections. In one study, connected technology was shown to provide a 34% decrease in emergency response times [10]. Vehicle-to-vehicle (V2V) technology allows for drivers to know where the emergency vehicle will be.

Unfortunately, the normal procedure, for drivers is to move over to the right side of the road, is not always possible. Autonomous vehicle programming could replace the normal procedure of human vehicles by clearing a path on roadways for emergency vehicles through a virtual emergency lane (VEL). By having clear path to the scene in advance, emergency vehicles will have minimal delay due to congestion, reducing the average response time and saving more lives for time-sensitive cases, particularly in urban areas.

To show how CAV technology can reduce emergency response times, a Microsoft Excel® spreadsheet tool called ddEMSCAT (data driven Emergency Medical Services with Connected and Autonomous Technology), was created to implement the developed framework and estimate the benefits CAVs can provide. ddEMSCAT utilizes data, user inputs, and the framework developed to forecast mortality rates under different levels of CAV technology and market penetration. The framework is demonstrated on Fayette County, a mostly rural county that includes an urban area in the city of Lexington. The tool can be used by urban area governments to inform policy and ensure the technology's potential is achieved.

In many ways, EMS in Italy and the USA are similar. Standards of care and response times compare well. Eight to nine minutes response time to life threatening emergencies is a common standard in the two countries. However, goals in some European countries greatly exceed this standard response, with 4 minutes, 45 seconds being the standard of response time in Copenhagen, Denmark. Dispatch areas (catchments), range from 30,000 persons (Cyprus) to 2.5 million persons (Portugal). Dispatch areas (size) range even more widely, from a low of 250 sq. km. in Cyprus to 50,000 sq. km. in Estonia. Italy records 103 EMS services, each serving and average of 550,000 persons with catchment area average size of 3000 sq. km. [11]

2 METHODOLOGY

CAV technology presents the potential to drastically reduce response times by allowing emergency vehicles to better navigate congested urban areas. A data-driven framework is developed in this study to estimate how different levels of CAV technology can decrease emergency response times and lower mortality rates in emergencies. Data are acquired from NEMSIS (National Emergency Medical Services Information System) and KCTCS (Kentucky Community and Technical College System) for Fayette County, Kentucky EMS calls for January 2019 [12], LFUCG (Lexington-Fayette Urban County Government) addresses, roadways with speed limits, fire station locations and trauma center locations [3], KYTC (Kentucky Transportation Cabinet) HIS (Highway Information System) roadway types and traffic [13], and Google Maps typical traffic congestion for roadways [14].

Lexington-Fayette EMS run logs are joined to KCTCS records street addresses associated with each EMS call. These are next joined to LFUCG data including street addresses, all roads (with speed limits), fire station points, and trauma center points. Run times vary by congestion level and roadway type. EMS miles traveled by road type must be estimated, so an equation is defined to estimate run times by road type. Average congestion level by percentage is used to calibrate the travel time equation [14]. These estimations are then used to compare the response time under various degrees of market penetration of CAVs. Once the change in response time is calculated, effect on mortality is computed.

2.1 Data

An open records request was sent to the Kentucky Emergency Medical Services Information System [12] to retrieve data on typical EMS runs in Fayette County, Kentucky. The request featured three types of data, including times, locations, and other. The data requested had to follow the restrictions under the Health Insurance Portability and Accountability Act (HIPAA) and did not provide personally identifiable information. The complete data received included: call time, dispatch time, unit en route, unit arrives at scene, unit departs scene, unit arrives at emergency department, origin of dispatch, patient location, location of emergency, indication of patient transport to emergency department, status of light usage to and from scene, and type of injury or call.

After the approval of the data request, all EMS run data from January 2019 in Fayette County was received. The Fayette County data contained 3,995 total records, with 1,303 non-hospitalized runs and 2,692 hospitalized runs. Although the data included valuable information for this project, 371 records were either incomplete or non-emergency, and most of the records did not have an origin of dispatch listed for the emergency vehicle. An automatic vehicle locator enables the dispatch of the nearest ambulance for a call. However, the originating location cannot be determined without making an assumption. Therefore, records without starting points were assumed to originate from the nearest fire station. The NEMSIS and LFUCG data sets were joined within ArcMap GIS, which readily enabled the computation of EMS route distances.

Congestion levels were approximated for different times throughout the day using Google Maps time of day estimates [14]. Google uses three different colors to indicate traffic levels, including green for light congestion (> 50 mph for freeways), yellow for medium congestion, and red for heavy congestion (< 25 mph) [15].

2.2 Virtual emergency lanes

Typical driving conditions are less than ideal for emergency vehicles. In the USA, most drivers follow the laws and cede right of way emergency vehicles. However, some do not comply in time to prevent delay. By eliminating human indecision and error and incorporating advanced knowledge of emergency vehicle routes, CAVs could allow emergency vehicles to respond and drive to calls more quickly and safely than today. The concept advocated in this study is that of the VEL. As moving to the right side of the road is the best solution with human driven vehicles, CAVs can analyze the situation and create space to augment or facilitate current rule following. The VEL potentially creates more space and allows EVs to pass with less impedance. With heterogeneous or fully autonomous fleets, connected vehicles will be able to create more space for EVs as compared to existing human driven non-connected systems. The two factors most impacting the performance of VELs are roadway type (geometry) and market penetration of CAVs. In this study, roadway types include freeways, five or seven lane roadways with center two-way left-turn-lane (5/7 CTWLTL), four lane roadways with left-turn lane at intersections, four lane roadways without left-turn lane at intersections, and two-lane road without left-turn lane at intersections. Three CAV market penetration scenarios are studied: 0%, 50%, and 100%.

EVs do not typically use freeways and interstates for response routing in urban areas. However, some EVs do make use of them, especially for non-emergency hospital transports or longer distances to a scene. The heaviest traffic congestion generally occurs on major arterial roadways, such as a divided roadway with barriers and left-turn lanes at intersections or divided roadways with a two-way left-turn lanes (TWLTL). The current study included two major Lexington, KY five/seven-lane roadways with dense traffic and multiple signals (South Broadway Street and Nicholasville Road).

2-Lane roadways with a TWLTL are similar to 4-lane roadways with TWLTL, but congestion is usually lighter, and space is limited for EVs. The roadway consists of a bulb to create enough space for two lanes at the intersection, while the rest of the roadway only contains two lanes throughout. Due to the usual designation of two-lane roadways as minor arterials or collectors, the signals associated generally give more green time to the cross street, creating more red time in the direction of the two-lane. CAVs have potential to improve two-lane roadways with left-turn lanes as well.

The final roadway type is a two-lane road without an LTL at intersections, usually found in suburban areas and neighborhoods. Considered as collectors or local roads, the higher ratio of green time generally goes to the cross street, limiting the amount of green time for the two-lane without left-turn lane roadways. The shoulders, if any, are generally narrower on these streets as well, requiring vehicles in both directions to leave the right-of-way or run a signal to accommodate an EV. Human drivers do not know the intended route of the EV, making communication difficult. With communication, CAVs will be able to make a more appropriate response to clear the roadway for an EV. Fig. 1 displays three scenarios for 2-Lane roads without a left-turn lane. The scenarios depict three levels of market penetration of CAVs and indicate the friction with human drivers versus the ease of coordination possible through VELs.

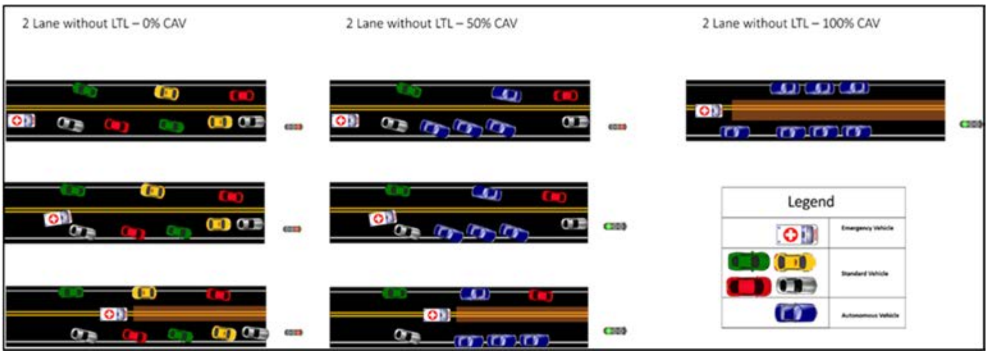


Figure 1: 2-lane roadway scenarios with virtual emergency lanes.

2.3 ddEMSCAT

To forecast the number of potential lives saved due to quicker response times enabled by CAVs, the research team developed ddEMSCAT (data driven Emergency Medical Services with Connected and Autonomous Technology). This spreadsheet-based tool combines data from EMS services, roadway characteristics, and forecasts of CAV market penetration. This section describes the framework and the implementation of the tool.

The primary contribution of ddEMSCAT is the travel time estimation of EMS through various levels of CAV market penetration. ddEMSCAT computes EMS travel time and number of patients affected, as shown in the flowchart of Fig. 2. Although the tool is data driven, certain assumptions must be made, especially as related to the market penetration of CAVs. Using Lexington EMS data from January 2019, an example application of the tool calculates time savings and potential number of lives saved.

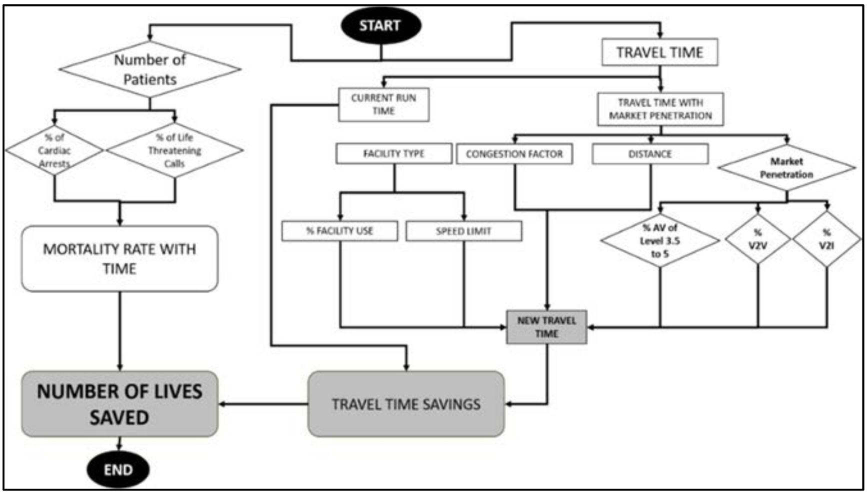


Figure 2: ddEMSCAT flow chart.

As the benefits of CAV manifest via reduced run time, calculations are made for various types of roadways, times and origins/destinations of emergency calls. Using typical run information ddEMSCAT can approximate the response times of today. For each run, a set minimum amount of time is required to initiate the run as well as to exit the vehicle and arrive on scene. From the Lexington data, this set time is taken as 1.2 minutes. This constant allows for one minute to leave the station after reporting en-route, and 0.2 minutes (12 seconds) to slow down at the scene and reporting “at-scene.” Also factored into the minimum response time is travel time at free flow speed, which is taken as the distance to the scene dividing by the speed limit plus 10 mph, the maximum permitted EV speed. See eqn (1)

$$Open\ Road\ Response\ Time\ (min.) = \frac{L}{SL+10mph} x\ 60 + 1.2, \tag{1}$$

where L = Length (miles) and SL = Speed limit (miles per hour).

Under light traffic conditions, Eqn 1 remains the same, but medium and heavy congestion will cause slower response times. Since Google Maps (source of ddEMSCAT typical travel times) provides a range, rather than an exact speed, the midpoint of the range is used to represent each traffic condition. For medium congestion, 37.5 mph is used to represent speed of a freeway link. Since 37.5 mph is 75% of the speed limit, 0.75 is added to the formula for medium congestion levels. Likewise, 25% is used for the heavy congestion, since the center point is 12.5 mph for the 0 to 25 mph range and 12.5 is 25% of 50 mph. Eqns (2) and (3) represent the EV free flow speed for medium and heavy traffic conditions respectively, allowing for the EV to maintain a 10-mph speed advantage over the normal speeds of vehicles.

$$Medium\ Traffic\ Response\ Time = \frac{L}{SL * 0.75 + 10mph} x\ 60 + 1.2 \quad (2)$$

$$Heavy\ Traffic\ Response\ Time = \frac{L}{SL * 0.25 + 10mph} x\ 60 + 1.2 \quad (3)$$

Signalized intersections also delay EVs during response. Red signals require the vehicles to come to a complete stop before proceeding through, while at green signals the emergency vehicle may continue with minimal disruption. Eqn 4 shows the estimated amount of time it takes to clear a signalized intersection during a green phase and eqn 5 shows the extra time when a red phase is incurred. EVs must begin to decelerate before the intersection and travel 10 mph through a 250-ft approach, coming to a stop at the intersection. Entering a red signalized intersection takes roughly 22 seconds (17 seconds for deceleration and 5 seconds to come to a complete stop). The acceleration time to reach the desired vehicle speed from eqns 1 through 3 takes eight seconds for ambulances. For green phases, simply traveling at 10 mph through the intersection (unless making a turn) will take 17 seconds. The constants for red and green phases are added to the equation, and a key input is the amount of green time for each roadway. Green time varies for every intersection, but for this study, major roadways are assumed to receive 67% of green time due to the typical volume/capacity ratio, while the minor roadways receive the remaining 33%. Although the green ratio is shown, the signal is not necessarily green the entire time. Red and yellow time are factored into each signal with a three-minute cycle length, indicating 62.5% green for major roadways, 37.5% red for major roadways, 29.2% green for minor roadways, and 60.8% red for minor roadways.

$$Green\ Phase\ Intersection\ Time = N * (Green\ \%) * \frac{Clearance\ Time}{60\ sec/min} \quad (4)$$

$$Red\ Phase\ Intersection\ Time = N * (Red\ \%) * \frac{Clearance\ Time}{60\ sec/min} \quad (5)$$

where N = number of intersections per functional class of roadway.

The NEMSIS data, LFUCG data, and HIS data for Fayette County were used to compute estimates of CAV benefit. Due to the unknown starting points for some runs, an assumption is made that every call originates at the nearest fire station housing EMS. Once the distances are calculated, the average response times are computed. Knowing the average run time and time to en-route, ddEMSCAT compares the calculated run time to the average run time, which can then be used to estimate the number of lives saved through time reductions.

Depicting the distances covered by EMS by facility types is challenging because calls occur everywhere. In ddEMSCAT, the HIS from the KYTC is used to estimate EMS mileage on each facility type. HIS shows how many miles of each facility are available in each county. With the mileage of each facility, it is possible to compute the percentage of roadway type each response would require. In Fayette County, only 10% of roadways are freeways, while their VMT is much higher than 10%. With the percent of mileage and speed limit for each facility, the free flow speed can be calculated for EVs.

The time of calls is important for calculating run time. When congestion is light, the EV will obviously have a faster response than calls during heavy congestion. This portion of ddEMSCAT is the last data-driven component. Knowing the percent of each congestion level, the EV response time is calculated with 0% CAV market penetration and compared to the actual (current) average run time from Fayette County. Since market penetration is speculative, the user can from 0% to 100% the market penetration of both autonomous vehicles and connected technology. As only higher levels of automation have the ability to respond to EVs without human interaction, only levels 3.5 to 5 have a user market penetration input cell.

Once all the data and speculative cells are filled, the time savings calculator runs through the average response distance, roadway facilities data, traffic congestion factors, market penetration, and finally the travel time equations to calculate the travel time without CAVs and time with CAVs, finally showing the time savings. The calculations for time savings are indicated in eqns (6)–(10)

$$Travel\ Time\ (TT)\ @\ FFS = Facility\ \% * \frac{Distance}{SL + 10} * 60, \tag{6}$$

$$\%\ TT\ Savings = \left(1 - \frac{TT\ @\ FFS}{TF}\right) * MP, \tag{7}$$

where MP = % market penetration and TF = travel time with traffic.

$$Calculated\ Travel\ Time = (1 - \%\ TT\ Savings) * TT\ @\ FFS. \tag{8}$$

Total travel time for runs can be computed as shown in eqn (8).

$$Total\ Travel\ Time\ = \sum TF * \%\ of\ Mileage, \tag{9}$$

$$Time\ Saved = Travel\ Time\ Today - Travel\ Time\ with\ CAVs. \tag{10}$$

The next component shown in Fig. 2 related to patients. The number of patients is determined by area and time period. The data for this study was limited to Fayette County, Kentucky for January, 2019. Within that month, there were 3,995 EMS runs. The patient cells are populated with 15% non-cardiac arrest, life threatening and 9.7% cardiac arrest patients. The remaining 75% include other calls, still seeking hospital care, yet the injuries or illnesses are not considered to be as time sensitive. Eqn (11) shows the procedure for estimating the number of time sensitive patients. The numbers show the minimum of number of lives saved based on the 1–2% mortality rate for every untreated minute of non-cardiac, life threatening patients and a 7–10% mortality rate for every untreated minute of cardiac arrest patients.

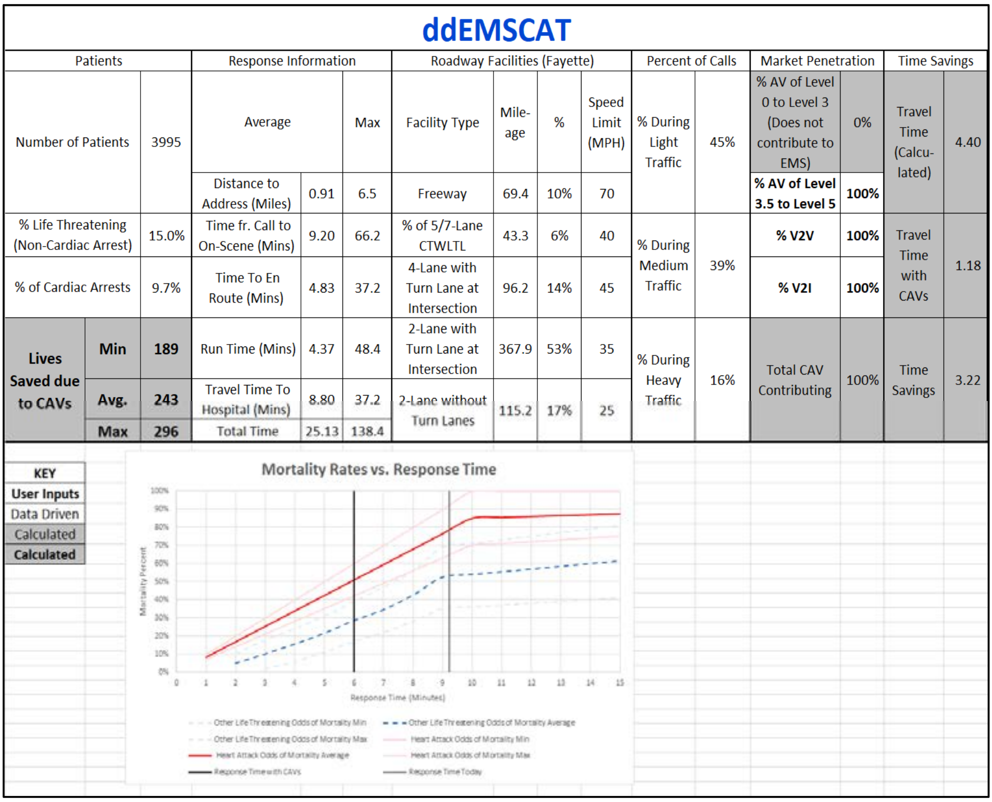
$$TSP = P(CA\% + OTS\%), \tag{11}$$

where TSP = time sensitive patients; P = number of patients; CA% = cardiac arrest percentage; and OTS% = other time sensitive percentage.

The final portion of Fig. 2 shows the link between travel time and patient data. With the maximum, minimum, and average mortality rate calculated for both cardiac arrest patients and life threatening, non-cardiac arrest patients, the total number of lives saved is bolded in the gray box, displayed in Fig. 3. The number of lives saved is calculated using the mortality percentage at the response time multiplied by the number of life-threatened patients and the new travel time, shown in eqn (12)

$$Mortality = TT * mortality\ \% * Number\ of\ Time\ Sensitive\ Patients, \tag{12}$$

where TT = total travel time.



ddEMSCAT

Patients			Response Information			Roadway Facilities (Fayette)				Percent of Calls		Market Penetration		Time Savings	
Number of Patients		3995	Average		Max	Facility Type	Mile-age	%	Speed Limit (MPH)	% During Light Traffic	45%	% AV of Level 0 to Level 3 (Does not contribute to EMS)	0%	Travel Time (Calcu-lated)	4.40
			Distance to Address (Miles)	0.91	6.5	Freeway	69.4	10%	70			**% AV of Level 3.5 to Level 5**	**100%**		
% Life Threatening (Non-Cardiac Arrest)		15.0%	Time fr. Call to On-Scene (Mins)	9.20	66.2	% of 5/7-Lane CTWLTL	43.3	6%	40	% During Medium Traffic	39%	**% V2V**	**100%**	Travel Time with CAVs	1.18
% of Cardiac Arrests		9.7%	Time To En Route (Mins)	4.83	37.2	4-Lane with Turn Lane at Intersection	96.2	14%	45			**% V2I**	**100%**		
Lives Saved due to CAVs	**Min**	**189**	Run Time (Mins)	4.37	48.4	2-Lane with Turn Lane at Intersection	367.9	53%	35	% During Heavy Traffic	16%	Total CAV Contributing	100%	Time Savings	3.22
	Avg.	**243**	Travel Time To Hospital (Mins)	8.80	37.2	2-Lane without Turn Lanes	115.2	17%	25						
	Max	**296**	Total Time	25.13	138.4										

KEY
User Inputs
Data Driven
Calculated
Calculated

Figure 3: ddEMSCAT interface.

The framework of ddEMSCAT is indicated by the equations shown above. The tool was designed to be straightforward and user-friendly. Fig. 3 shows the ddEMSCAT user interface. User inputs are bold with a white background. The data driven components have a white background and regular text, the calculated portion has a gray background, and the calculated section with number of lives saved has a gray background and bolded text.

The first category is for patient data. The user has the option to place in the number of patients and the percentage of cardiac arrest or percentage of non-cardiac arrest life threatening patients. The numbers in the tool are data-driven from Fayette County. The bottom portion of the patients category shows the minimum, average, and maximum number of lives saved due to the market penetration of CAVs based on the mortality rates and time saved.

The second portion includes response information. The average category shows the average distance traveled to a call, response time, run time, travel time to hospital, and total time. The time to en-route cannot be manipulated by CAVs, but everything else can be reduced by the market penetration of CAVs. The minimums for all the calls are not shown because the category is filled with zeros, as the EMS units were already on scene. An example of an EMS unit being on scene immediately is for an event with large crowds where EMS units are stationed at the event for precaution.

The third portion of ddEMSCAT includes roadway facilities. Since the VMT was not shown for EMS units, the mileage of roadways is shown instead. The number of miles of each roadway is shown with the appropriate speed limit for each roadway type. All the data in this section can be manipulated for different municipalities, but this section includes data from Fayette County.

The fourth portion of ddEMSCAT is the percent of calls. The percent of calls during different levels of traffic congestion was found from Google Maps data for each day of the week in Fayette County. The user as the ability to change the traffic congestion percentage for different municipalities, which could then show the time savings for different congestion levels.

The fifth portion of ddEMSCAT is more speculative. Market penetration of future CAVs is unknown as of today. Thus, the user as the option of changing the percentage of AVs on the roadways, as well as the connected technology percentage. V2V and V2I each contribute 25% of the market penetration, while AVs contribute 50%, eliminating human error.

The final section presents the time savings. All of the user inputs are calculated and shown to calculate the response time of EVs with human drivers and the response time with CAVs. By subtracting the travel time with CAVs from the time without CAVs, the total time saved is shown. The time saved is then added to the average time to en-route to find the total response time. The total response time is placed into the final equation to find the total number of lives saved.

ddEMSCAT users can fill in their own data and speculations to estimate the time savings with CAVs, as well as the number of patients potentially saved. Thus, the contribution of the study is both a framework for analysis and an example using as much real-world data as can be expected in any local community. Of course, the results can be scaled up to regional, state or national levels given appropriate data and assumptions.

3 RESULTS

As of today, 45% of calls are completed within the five-minute critical time, while 41% exceed the eight-minute critical time. The study indicates that for Lexington, a savings of 17% in response time is possible with a CAV market penetration of 35%. For 50% penetration of connected and 50% autonomous vehicles, the potential time savings could attain 68% in decreased run time, approximately 3.2 minutes in Lexington. This could result in an average response time of 6 minutes, still higher than the 5-minute critical time but lower than the 8-minute critical time. Fig. 4 gives provides a visualization of call times with market penetrations of 0%, 50%, and 100%. As can be seen, as the market penetration increases, the number of calls over five minutes and eight minutes decreases within the city.

Travel time savings are important, but the goal is to save lives. To compute the effect of the savings on mortality, the bottom section of Fig. 3 shows the estimated mortality rates over time with the present response times as compared to response times with CAVs. The figure depicts a full market penetration of CAVs which brings the response time down from 9.2 to 6 minutes. Note that the average mortality rate of cardiac arrest patients at 9.2 minutes is 78%, while the average mortality rate for other life-threatening patients is 53%. At 6 minutes, the mortality rates for the two cases decrease to 51% for cardiac arrests and 29% for other life-threatening conditions. While these percentages are speculative maximums, the ddEMSCAT framework allows the user to input data into the tool to create a forecast for different cases and areas.

Figure 4: Number and location of ambulance calls over critical response times with different market penetration levels of CAVs.

4 ITALIAN IMPLICATIONS

On the face, this work would seem to be equally applicable in Italy or any industrialized country's urban areas. Key is the availability of data to populate the inputs to ddEMSCAT for the computation of potential savings. While we were not able to obtain Italian data in time for publication of this paper, there are several differences between USA and Italian EMS services that could (a) make results more or less accurate, and (b) require additional factors in ddEMSCAT. For example, Italian EMS follows the Franco-German Emergency Medical Services System (FGS), where the main motto is to "Stay and Treat", whereas in the USA, the Anglo-American emergency Medical Services Systems (AAS) is followed, which aims at "Transport and Treat" [16].

In the USA and in England, the crews in an ambulance serve to stabilize the patients before they can be transported to a nearby facility for further treatment. But in Europe, and Italy in our case, ambulances are so well equipped that they are prepared for treating a critical patient on site. But to do that, the crews and staff need to be very well trained [17]. This difference between Italian and US services does not directly affect response time, but there are likely indirect effects. For example, as the Italian ambulance staffed by a physician is perhaps better suited to enable a better outcome for an individual patient, if the number of units per capita is fewer, dispatch areas could be larger. However, due to the higher population density of Italian cities and regions as compared to the US, the areas may in fact be smaller.

A study comparing EMS services in the US and EU reports Genoa, Italy has less than a quarter or the EMS Transports as Richmond, Virginia, USA. Obviously, if this ratio is typical and representative of life-threatening EMS calls, the benefits of reduced response times as calculated by ddEMSCAT would be much smaller in Italy. However, the same study reports that Genoa has 25% more attempted EMS cardiac arrest resuscitations [18]. The population of the Genoa area is approximately 20% greater than that of the Richmond MSA, suggesting that the ratio of life-threatening calls between the two cities is probably closer to parity. These and other differences require further study but could be accounted for in the ddEMSCAT framework.

5 CONCLUSIONS

The results of this work indicate the potential for CAVs reducing emergency response times in urban areas by following rules, setting examples, and ultimately leading to the introduction of the virtual emergency lanes, especially near intersections. This work addressed several of the theoretical boundaries using current data and attempting the future forecast with the potential of CAVs. The tool developed for estimating these benefits could be enhanced with the consideration of binning response times. Longer response times would likely see the most dramatic change under CAV technology scenarios, though critical improvements to key response times may have the most profound effect on lives saved. For instance, most time-sensitive emergency conditions are sensitive to the five-minute and eight-minute response marks.

By assuming different levels of market penetration and understanding the ways EVs and CAVs could potentially interact, we can see that CAVs can reduce the average emergency response time by over three minutes. In our case study of Lexington, Kentucky USA, this could result in a reduction in cardiac arrest mortality as well as non-cardiac arrest and life-threatening mortality rate by 35%.

This study has limitations typical in any forecast of future technology. Lack of data necessitates many assumptions, including time required for proper care, locations of calls, and simulations. This report and ddEMSCAT lay out a framework for investigating emergency response times facilitating the pursuit of additional needed research into off-system impacts of CAVs on public health.

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