# Informed Traffic Signal Preemption for Emergency Vehicles

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### Abstract

Emergency vehicle traffic light preemption systems are extended by using more detailed predicted trajectories to provide favorable changes of signals. The location of the emergency vehicle is tracked and traffic signals on the requested travel route are contacted and switched to become green in time, before the emergency vehicle reaches the selected intersection. The resulting time to destination obtained by our simulation is compared to a control simulation without preemption. In simulations, when an emergency vehicle reaches a red light, a delay of five seconds is considered to happen naturally to the vehicle's journey due to preventive driving. The switching of colors requires an eight second green light warning, also for reasons of safety. According to the improvements shown by our simulations, given the number of seconds gained from the knowledge of trajectory details and information passing with the traffic lights, from the 356,000 out-of-hospital cardiac arrests in the United States per year, approximately 3,000 lives would be saved. This travel time gain can also significantly decrease the anxiety and improve the mental health of surrounding involved participants including family, health workers, and other bystanders thereby improving the quality of services that health workers can provide. The change of lights exploits knowledge of compatibility between paths allowed by current default light combination and the path of the emergency vehicle to save essential safety buffer seconds.

## Introduction

As more traffic appears on roads and more complex traffic modes are created, emergency vehicles (EMVs) are confronted with more obstructions. For each extra minute emergency responders take, the chances of survival decrease by 5.5% for out-of-hospital cardiac arrest victims (Larsen et al. 1993). In 2007, the chances of survival after each minute without CPR had been found to decrease by $7-10\%$ (Ibrahim 2007). Similarly to cardiac arrests, for rescues in fire evacuations $0.00035$ lives could be saved per incident for every minute gained (Jaldell 2017). Each red light encountered causes the EMVs to lose vital seconds. Although EMV preemption systems with acoustic, optical, radio frequency, and global positioning systems have been introduced in a few cities across the first world countries, installation has been slow due to cost of material and maintenance. Additionally, current preemption systems can experience unwanted interference from weather conditions and physical constraints. This study aims to solve the problem by developing a preemption system that exploits more detailed predicted trajectory data and known traffic to control traffic signals ahead of the EMV all while expecting safe preventive driving and signal color combination changing policies with large safety margins. The evaluation is achieved through a detailed discrete event simulation.



## Background

EMVs are permitted to exceed the speed limit and pass through intersections when the signals are not green. However, when crossing at a red signal, a preventive driver of an EMV slows down to prevent collisions with other vehicles from the default traffic whose drivers might not have heard the sirens. Consequently, this leads to dozens of precious seconds being lost. Policies with good safety margins prescribe, for changes of signal colors, a requirement of appropriate delays consisting of a minimal yellow light interval and a red clearance interval.

Hence, to better improve the response times, in some places, acoustic systems have been put in place. The acoustic signal preemption method functions by using the EMV siren to emit sound waves. The sound waves are then intercepted by a detection microphone located on the signal arm. When an EMV sends the corresponding acoustic signal, a preemption request is sent to the signal controller leading to the signal being changed (Paniati and Amoni 2006). Unfortunately, the wave form rapidly distorts over large distances and can easily be interfered by neighboring sounds.

Optical systems can alternatively also be used to signal traffic lights or gated entries concerning the arrival of a high-priority vehicle that needs to pass (Paniati and Amoni 2006). Modifications of different optical systems like the Tomar Strobecom II provide assurance that the light does not lose intensity over time (TOMAR 2024). Other optical systems use infrared lights such as the fast emergency preemption systems (FAST) in Japan (Miyawaki, Yamashiro, and Yoshida 1999). The majority of these optical systems will,

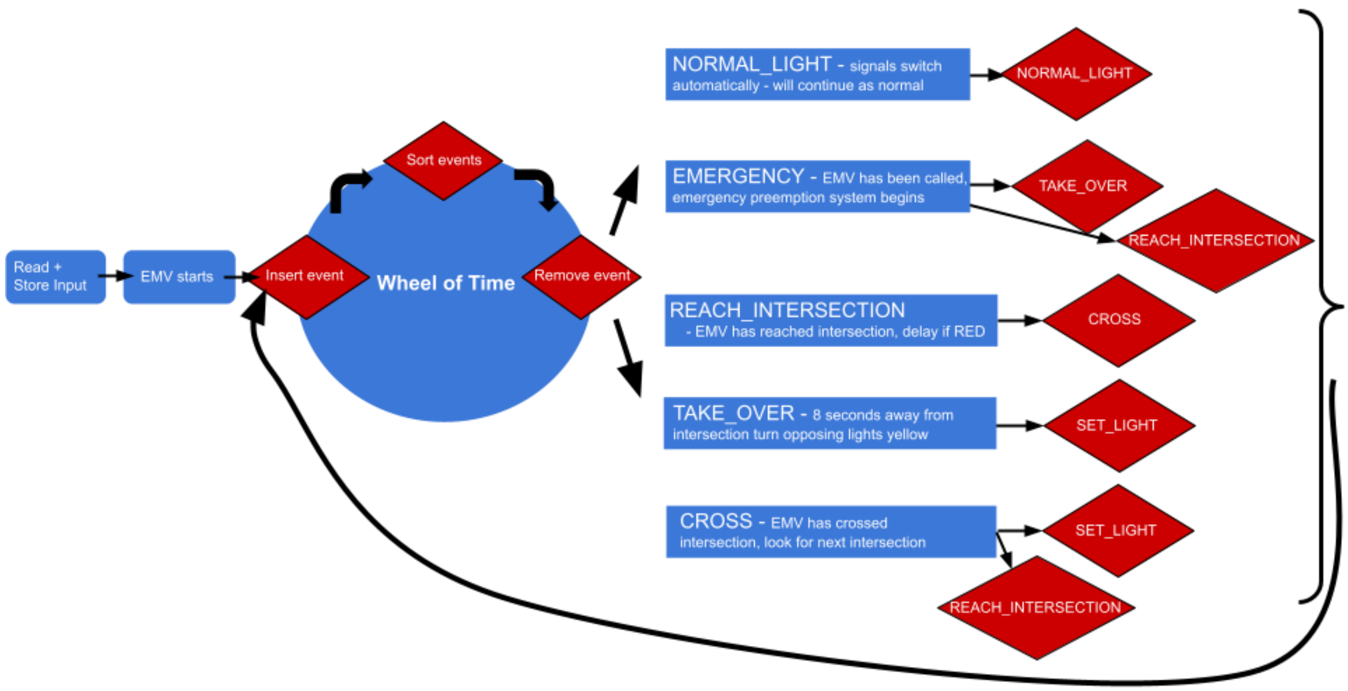


Figure 1: The evaluation uses a discrete event simulator.

however, struggle when intersections occur after a curve or physical obstruction.

The use of radio frequency identification (RFID) has also been exploited by emergency vehicles which emit radio activating signals for sensors on the traffic signal arms. When a specific RFID is detected, the preemption request proceeds to the signal controller (Paniati and Amoni 2006). The RFID tags can then notify the sensor when the EMVs have left the intersection and signals can return to their habitual function. The drawbacks of the radio systems are that they are in fact susceptible to electronic noise interference from other motorists. Each EMV must also be equipped with the emitter and each traffic arm needs to be equipped with the sensor, increasing cost of function.

Past approaches base the red lights schedule adjustment on the detection of the emergency vehicle in the intersection with various sensors. A mechanism to detect the vehicle based on vision with machine learning, using You Only Look Once (YOLOv8) technology, shows a 98% accuracy with 97.6% of precision (Noor et al. 2024). However, it also requires direct line of sight and it can only be certain that the vehicle approaches the given intersection when the emergency vehicle is on the last road segment. Moreover, it cannot predict the turn the emergency vehicle will take in the intersection.

An Internet-based communication of GPS-based intersection detection is used by a commercial preemption system, The Eliminator (Communications 2024). AI-based preemption systems use multi-agent simulations, and are a current direction of research (Bazzan 2005; Dresner and Stone 2008).

The Eliminator, is a commercial solution and discloses few in-depth details of its numerous functions but does reveal its use of a GPS-based system and 900 MHz radio. This combination of both the Internet-based communication of GPS detection and radio frequency identification is credited as the foundation of its implemented collision avoidance system (Communications 2024).

A conference dedicated to urban mobility and traffic simulation (SUMO) has been held since its first occurrence in May of 2013 in Berlin, Germany (SUMO 2013). It serves as a venue for the publication of multiple traffic simulation mechanisms, which could help support our future work with other evaluations of signal preemption systems.

## System Overview

As shown in Figure 1, the process proposed has two major components: acquiring the map and the predicted trajectory, and scheduling safe adjustments of any red signals to green at appropriate times on the EMV's route. Corresponding data structures store values including directions at each intersection, distance between intersections, and average speed of EMV on each segment. There is a unique ID tied to each segment and intersection.

The second component of the system consists of a scheduler that contacts each future intersection with lights and reprograms it to speed up the connection between the lanes traveled by the EMV. If the lights of the intersection happen to be compatible with the trajectory of the EMV when it plans to enter the intersection, no change is required, other than the blocking of the state to avoid preemption by a less important event. Otherwise, the original green lights are rescheduled to turn yellow and red five seconds before the EMV arrives, if possible. The 5 seconds are considered the minimal amount of time for stabilizing the traffic patterns and avoiding confusing other drivers that could act under impulse and endanger the safe traversal of the intersection by the EMV. These seconds are considered to be part of the yellow light interval. A following three seconds are dedicated to the red clearance interval.

An important source of speed-up for EMVs by this process is produced by the enabling of the co-habitation of the EMV's trajectory with other traffic lines that do not intersect. This enables the possiblity of skipping the five second extensions before the change of colors when the default configuration can allow for such co-habitations. This leads to a total gain which composes the five extra seconds and the other delay from the slowing down of the EMV.

The generation of improved trajectories can be achieved by training a neural network on history of patterns of traffic accumulated over multiple sessions of usage of the system. For instance, a predictor based on density of vehicles and accidents along the trajectory and adjacent roads within reachable distance. The five second delay can be tuned to an appropriate amount of time to be learned from history of barging-in by impatient drivers recorded in time by the system to minimize the delay while reducing undue foresight. Recommended speeds of the EMV in intersections where it enters on a red light can also be tuned based on surveillance of remaining traffic as reported by GPS and extra cameras aggregated in a centralized reasoning station.

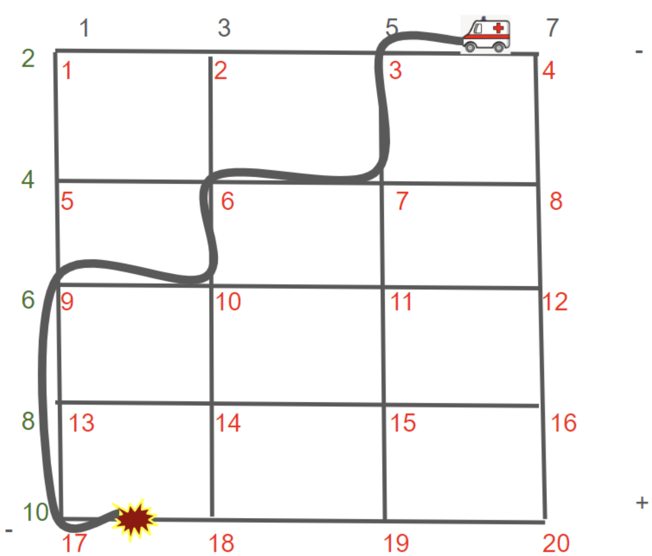


Figure 2: A map representation of one of the five simulation maps generated.

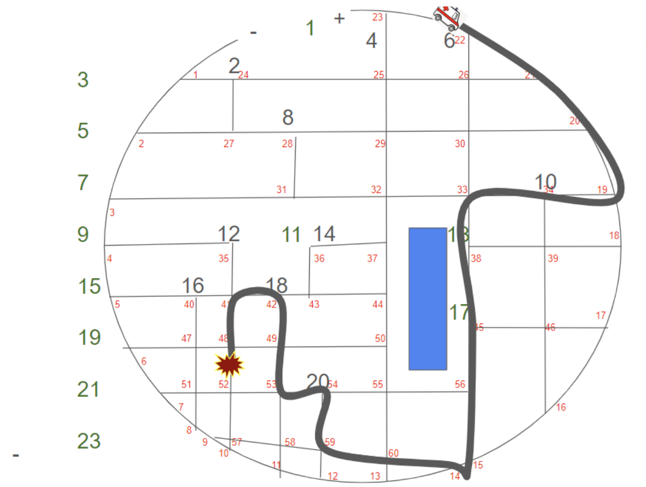


Figure 3: A map representation of the second of the five simulation maps generated.

## Experiments

The effectiveness of the new EMV preemption system was analyzed with two testing phases. First, the new EMV preemption system behavior was compared across five different benchmark maps.

The second phase included testing in each five simulated maps with five different starting times for each of them. The same five departure times were selected for each of the five simulated maps for consistency. Both phases testing compared the proposal against a control version where red lights were not modified. A five second delay is added to travel each time a red light is encountered.

Benchmark maps were created with a random number generator. Each had a randomly selected number of intersections, one of the intersections being a randomly selected number of feet away from an emergency vehicle location. Distances were randomly generated between 0 and 100,000 feet. Figure 2 shows the drawn representation of the values collected for the first of the five benchmark maps. The ambulance demonstrates the starting location of the emergency vehicle and the red distress signal shows the location of the emergency. The path follows a predicted trajectory established by the prediction component based on heuristics to minimize time to destination. Each road segment and intersection is labeled and includes negative and positive directions based on the EMV's direction of travel. Figure 3 illustrates similarly a drawn representation of the fifth of the five benchmark maps.

## Results

As observed in Figure 5, across the five simulations there was a net greater average percent of red lights causing delays when the emergency vehicle did not have preemption than when it did. This greater amount of delays is also represented in Figure 4 where across the five simulations the EMV reached its destination with traffic signal preemption with an absolute average percent difference of 1.017 sec-

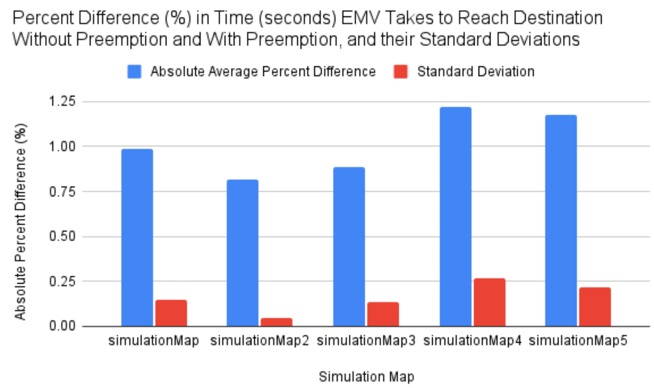


Figure 4: Absolute percent difference (%) in time (seconds) EMV takes to reach destination without preemption and with preemption and their standard deviations.

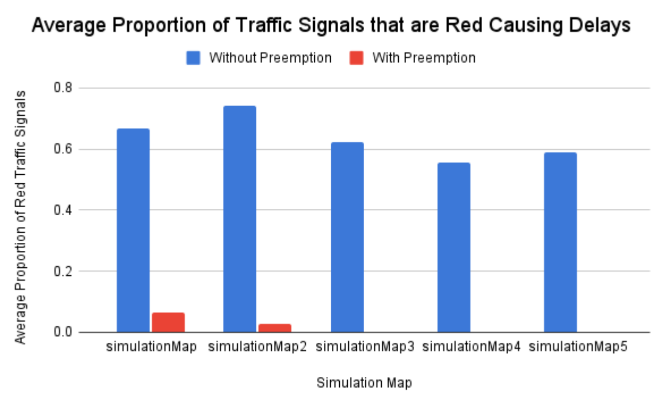


Figure 5: Average proportion of red traffic signals causing delays on route of EMV without and with preemption.

onds. The EMV was approximately 1% faster with preemption. Although the improvement brought by the new traffic signal preemption system seems minimal, in simulation map five, on average a whole 66 seconds were saved and over the five different maps, on average 39 seconds were saved.

When the EMV departed from its starting point at five different times, there was no significant difference recorded between the times ($p > 0.3$). However, between the control, without preemption, and the test with preemption, there was a significant difference ($p < 0.002$). This shows a statistically significant improvement in EMV time to destination with the new preemption system versus the control version. The 1% decrease in time spent traveling towards a location of an emergency may double when considering the trip back to the hospital if the EMV is an ambulance. If the delay at a red light is above 5 seconds, as other references consider, the improvement would grow accordingly.

The consequences of even modest delays in ambulance response times at traffic signals are severe, especially in emergency medical situations where every second counts. Such delays can have a major impact on patient outcomes, especially in time-sensitive illnesses such as heart attacks or serious injuries, when the timing of medical intervention can decide survival and recovery rates. Furthermore, these delays can worsen the patient's health, necessitating more complex medical measures later. Aside from the immediate health consequences, minor delays can cause worry and anxiety for patients and their families, influencing their overall experience with the emergency response system. These delays add to the pressure and urgency of healthcare workers' duties, potentially impacting the quality of care provided. The results and analysis of our study highlight the importance of effective emergency response systems for improving patient outcomes and healthcare delivery.

## Conclusions

Our goal was to evaluate a new preemption system exploiting the knowledge of the predicted trajectory to track an EMV throughout a route, turning necessary signals green. The 1% decrease in time spent traveling towards a location of an emergency is vital because for every extra minute, the survival rate for cardiac arrests and fire rescues rapidly diminishes. Additionally, the decrease in delays will improve psychological parameters of bystanders and medical practitioners improving the overall quality of care and response effectiveness. Because this new system does not require specialized emitters or receptors like other preemption systems, it provides a cheaper and more automatic alternative.

Future studies on this new preemption system would include implementing collision prevention with other EMVs that could be on the same trajectory. If two EMVs were approaching the intersection in conflicting directions, one could be chosen to go first based on priority of emergency. With appropriate knowledge representation models and sufficient data, better quality prediction of EMV trajectories can be learned from data gathered including traffic history and speeds of safe and unsafe crossings at red lights. This system could also adapt to different signal schemes for each intersection rather than the common signal scheme chosen for all signals and take into consideration the possibility of intersections with more than four incoming lanes.

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