Adaptive Traffic Management for Emergency Vehicles in Work Zones

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Abstract: A work zone is a section of road with closed lanes for maintenance, forcing vehicles to merge and creating congestion bottlenecks on the highway. Emergency Vehicles (EVs) are vital for incident response, with response times closely tied to fatality rates. EVs often face challenges when navigating work zones, and despite their importance, little attention has been given to improving their movement through these areas, highlighting the need for a system that enables quicker EV passage in work zones. While traffic management strategies are implemented in work zones, their effectiveness for EVs remains unexplored. This leaves a gap in understanding work zone management for EVs, ensuring their fast and safe passage. This paper proposes the ADAPtive Emergency MERGing (ADAPT-EMERG) algorithm to address this gap. This algorithm controls vehicles longitudinally for smooth merging into the open lane. It integrates merging approaches, headway adjustment between vehicles, and Variable Speed Limit (VSL) rules to set speed limits. Simulation results show that the ADAPT-EMERG algorithm reduces average travel times by 40%, minimises time loss for EVs by an average of 5%, and achieves a throughput increase across various traffic scenarios compared to the state-of-the-art strategies.

1 INTRODUCTION

A work zone is a section of roadway where certain lanes are closed for maintenance or construction (Meng and Weng, 2013). This reduction in capacity forces vehicles of both lanes to merge into a single open lane abruptly (Algomaiah and Li, 2022). This results in traffic congestion and a higher risk of crashes, especially rear-end and angle collisions caused by stop-and-go conditions and unsafe merging. Consequently, work zone safety and mobility have been researched extensively. The most well-known approaches for managing work zone merging are the LM and EM techniques. EM is the primary merging behavior in work zones, where drivers quickly move into the open lane when they notice a lane closure (Dixon et al., 1996), while the LM strategy encourages drivers to use all available lanes until they reach the merging point (Ramadan and Sisiopiku, 2018). Some studies have indicated that EM strategies perform better under uncongested traffic conditions (Kurker et al., 2014), while LM strategies are more effective in moderate to heavy traffic. However, other researchers have reported different results (Ramadan and Sisiopiku, 2016). The newly proposed New England Merge (NEM) strategy was developed to address the limitations of both the LM and EM strategies. NEM focuses on merging in work zones by controlling the longitudinal movement of vehicles, adjusting the gaps between them, and regulating their speed for smoother traffic flow (Ren et al., 2020b). Since the advent of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication, using Connected Automated Vehicles (CAVs) for merging applications has garnered significant interest (Golpayegani et al., 2021). A few recent studies have examined cooperative merging in work zones using V2I and V2V technologies to evaluate different merging strategies (Ren et al., 2020a; Cao et al., 2021; Algomaiah and Li, 2021). Enhanced

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cooperation in implementing the LM strategy can be achieved through information exchange between Connected Vehicles (CV) using Advanced Driver Assistance Systems (ADAS) and between CAVs through a control unit. Both CVs and CAVs utilize V2V, I2V, and V2I communication through Dedicated Short-Range Communication (DSRC) technology (Abboud et al., 2016). Previous research primarily concentrated on using CV to improve compliance rates (Ghanadbashi et al., 2024a), but did not fully address merging strategies or changes in gap acceptance and cooperation, which are key benefits of CV technology (Algomaiah and Li, 2022; Liu et al., 2017).

Merging in the work zone creates significant traffic safety issues, highlighting the urgent need to reduce the impact of accidents through effective measures, such as reducing accident response time. Rapid medical attention within the "golden hour" is crucial for the best recovery outcomes (Stewart, 1990). Emergency Vehicles (EVs), including fire trucks and ambulances, are essential to Emergency Medical Services (EMS) systems, transporting vital equipment and personnel to the accident sites for first aid. Minimizing response time for EVs is crucial, yet they often face obstacles from other vehicles on regular roadways and highways, causing delays. The unpredictability of traffic flow on highways exacerbates these issues, and despite its importance, this challenge is not yet adequately addressed (Ghanadbashi and Golpayegani, 2022; Ghanadbashi et al., 2024b; Wu et al., 2020; Mikolasek et al., 2024). Dynamic environments require adaptive approaches to align operational rules with evolving objectives (Riad et al., 2022; Guo et al., 2023). NEM strategy is proposed to enhance work zone traffic management using CAV features. Unlike EM and LM controls, NEM is designed to accommodate different traffic demand conditions without frequent adjustments based on traffic flow variations and takes advantage of CAV technology to enhance work zone traffic management (Kang et al., 2006). However, this approach does not account for the distinct characteristics of different vehicle types, including their varying sizes, speeds, and priorities. This limitation is particularly concerning given the critical nature of EVs' tasks. EVs require fast and unobstructed passage through traffic to respond to emergencies as quickly as possible. The current methods for managing merging in work zones do not provide the necessary accommodations or prioritization for these vehicles, potentially delaying their arrival at critical destinations and compromising the efficiency of emergency services. Therefore, there is a significant need for a more comprehensive approach that addresses the specific requirements of EVs to ensure they can reach their destinations promptly and perform their crucial functions without delay. One of the main challenges is the lack of communication and centralized control among drivers, which makes self-organization difficult. Hence, using CAVs, an efficient control algorithm for clearing lanes for EVs is required.

This paper focuses on the issue of addressing the particular needs of EVs for delivering emergency services, passing through a work zone on a highway while maintaining the overall network's efficiency. In this paper, we propose the ADAPtive Emergency MERGing (ADAPT-EMERG) algorithm, a rule-based method designed to optimize vehicle behavior in real-time to enhance the efficiency of EVs. The proposed algorithm aims to improve the efficiency and safety of lane merging operations in work zones by leveraging the advanced communication and automation capabilities of CAVs. This algorithm regulates gap acceptance, speed adjustments, and lane changes for regular vehicles based on real-time information from the environment. By guiding normal vehicles to adjust their speed and positioning, ADAPT-EMERG not only ensures a clear and efficient path for EVs to pass through work zones without unnecessary delays but also maintains the overall efficiency of the system and minimizes disruptions for other vehicles. This balance ensures that EVs prioritization does not compromise the smooth flow of regular traffic. The algorithm's effectiveness is evaluated through extensive simulations, demonstrating its potential to significantly improve traffic operations in mixed CAV and EV environments. The structure of this paper is as follows: In Section 2 the baseline model is explained, followed by the proposed model in Section 3. The results of the ADAPT-EMERG algorithm are then compared to a baseline in Section 4. The paper concludes with a summary of the findings, a discussion of the limitations, and suggestions for future research in Section 5.

2 BACKGROUND

In this paper, we extend the NEM and also use it as a benchmark for evaluating the performance of our proposed algorithm. The NEM is based on the Wiedemann 99 car-following model. Table 1 lists the variables used in the Wiedemann 99 model and NEM control strategy.

As shown in Figure 1, the NEM strategy includes two metering zones and one merging zone. The lengths of Metering Zones I and II are fixed and have been determined through empirical analysis. In Me-

Table 1: Description of Variables.

Parameter	Description	Unit
CC0	Desired stop distance between vehicles	m
CC1	Desired time gap kept by the following driver	s
CC2	Additional space for the following vehicle	m
dx	Distance between leading and following vehicles	m
acc	Rate of vehicle acceleration	m/s^2
v	Vehicle speed	m/s
d_{x_1}	Required distance in the open lane	m
d_{x_2}	Gap between vehicles in the closed lane	m
d_{x_3}	Distance in the closed lane	m
$CC1_{\text{open}}$	Desired headway in the open lane	s
$CC1_{\text{closed}}$	Desired headway in the closed lane	s
V	Speed limit within metering zones	m/s

tering Zone I, vehicles increase their headways, and lane changes are prohibited. In Metering Zone II, vehicles in the open lane maintain normal behavior while those in the closed lane adjust to keep safe distances. In the merging zone, lane changes are allowed.

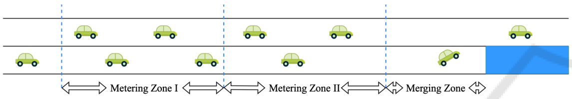


Figure 1: Architecture of NEM approach.

2.1 Longitudinal Control in Metering Zone I

To ensure safety, the gap between vehicles in the open lane is adjusted using Equation 1, illustrated in Figure 2.

$$d_{x_1} >= d_{x_2} + l_2 + d_{x_3} \tag{1}$$

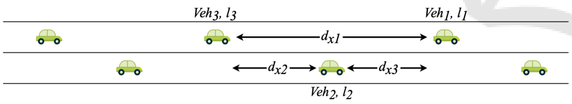


Figure 2: Longitudinal control in Metering Zone I.

Using the Wiedemann 99 model, the minimum value for d_{x_1} is:

$$d_{x_1} = CC0 + CC1_{open} \times V + CC2 \tag{2}$$

For vehicles in the closed lane:

$$d_{x_2} = d_{x_3} >= CC0 + CC1_{closed} \times V + CC2 \tag{3}$$

For these equations, V is the speed limit (20 m/s), $CC0$ is 1.5 m, $CC1_{closed}$ is 1.7 s, and $CC2$ is 3.9 m. $CC1_{open}$ is set to 3.9 s.

2.2 Longitudinal Control in Metering Zone II

Metering Zone II aims to increase throughput. Vehicles in the closed lane should travel near the midpoint between consecutive vehicles in the open lane. Depending on vehicle positions, two scenarios arise:

In the first case, when $d_{x_4} >= d_{x_3}$, acceleration is determined by Equations 4 to 7.

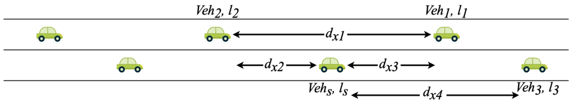


Figure 3: Longitudinal control in Metering Zone II (first case).

If the gap between the subject vehicle and the leader in the open lane is larger than the gap between the subject vehicle (Veh_s) and the follower in that lane (Veh_3), and the subject vehicle's speed exceeds the average speed of the follower (Veh_2) and leader (Veh_1) by more than 3 m/s, the acceleration of the subject vehicle is determined using Equation 4:

$$d_{x_3} > d_{x_2} \quad \text{and} \quad v_s > (v_1+v_2)/2+3 : acc = max(-\sqrt{d_{x_2}}, (v_1+v_2)/2 - v_s) \tag{4}$$

Based on the values of the variables, the appropriate acceleration formula is applied using Equations 5, 6, and 7:

$$d_{x_3} > d_{x_2} \quad \text{and} \quad v_s <= (v_1+v_2)/2+3 : acc = min(\sqrt{d_{x_3} - d_{x_2}}, 2) \tag{5}$$

$$d_{x_3} <= d_{x_2} \quad \text{and} \quad v_s < (v_1+v_2)/2 : acc = min(-\sqrt{(d_{x_2} - d_{x_3})/2}, (v_1+v_2)/2 - v_s) \tag{6}$$

$$d_{x_3} <= d_{x_2} \quad \text{and} \quad v_s >= (v_1+v_2)/2 : acc = max(-\sqrt{(d_{x_2} - d_{x_3})}, -2) \tag{7}$$

In the second case, when $d_{x_4} < d_{x_3}$, two sub-cases are considered:

$$d_{x_2} + d_{x_4} >= 2 \times d_{x_u} : acc = Wiedemann(CC1 = 1.7) \tag{8}$$

$$d_{x_2} + d_{x_4} < 2 \times d_{x_u} : acc = Wiedemann(CC1 = 10) \tag{9}$$

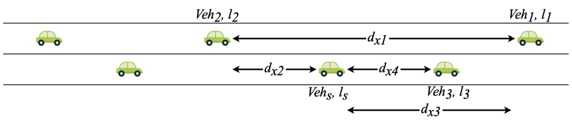


Figure 4: Longitudinal control in Metering Zone II (second case).

The first sub-case applies when the gap is sufficient for merging without affecting the open lane, using the default Wiedemann 99 model (Equation 8). When the gap is insufficient, the second sub-case is used (Equation 9).

3 METHODOLOGY

The proposed ADAPT-EMERG algorithm (Algorithm 1) is designed to address the inefficiencies and safety concerns identified in the literature. The algorithm operates in distinct phases, depending on the presence and position of the EV, adjusting traffic flow, headway spacing, and VSL rules to ensure safe and efficient navigation. This method proposes a rule-based mechanism to enhance the performance of EVs by guiding regular vehicles on how to dynamically adjust their speed limits, lane positioning, and headway spacing to accommodate the EVs' passage through work zones. By leveraging the communication capabilities of CAVs, the algorithm continuously receives real-time updates from the environment and communicates the necessary adjustments in a real-time manner.

Phase 1: No EV Present

In the absence of an EV, the system functions normally according to NEM. NEM is applied to all vehicles in the work zone area and speed limits and headway spacing are maintained at their default values. During this phase, no special instructions are applied, and the traffic system behaves as it would in a typical work zone scenario without the presence of EVs (refer to Algorithm 1, lines 28 to 31).

Phase 2: EV Detected Before Metering Zone

When the presence of an EV is detected in the area before the metering zone, the EV is directed to merge into the open lane as long as safety conditions, such as sufficient headway and no blockages, are met. This early merge ensures that the EV can proceed through the work zone with minimal interference (refer to Algorithm 1, lines 4 and 5).

Phase 3: EV Detected in the Metering Zone

When the presence of an EV is detected in the metering zone, the algorithm temporarily overrides the NEM approach to prioritize the passage of the EV. If the EV is in the open lane, the speed limit in that lane is increased to 30, while the speed limit in the closed lane is reduced to 10. These values were determined by testing a range of speed limits from 5 m/s to 50 m/s, in increments of 5 m/s. The chosen values of 30 m/s and 10 m/s were identified as optimal based on their ability to achieve the most significant improvements across various performance metrics. This encourages vehicles in the closed lane to slow down, allowing the EV to pass through more easily. If the EV is in the closed lane, the speed limits are reset to their default values, with both lanes maintaining a speed limit of 20 (refer to Algorithm 1, lines 7 to 13).

Phase 4: EV in the Merging Zone

When the EV enters the merging zone, the algorithm dynamically adjusts the headway between vehicles based on the EV's lane. If the EV is in the closed lane, vehicles in the open lane are instructed to increase their headway to 3.9 seconds, creating sufficient space for the EV to merge safely. Once the EV successfully merges into the open lane, and if another EV is also present in the open lane, the headway is reduced to 1.7 seconds to allow the first EV to pass through quickly. After the EV has passed, the headway spacing returns to default values to facilitate normal traffic flow and enable the merging of vehicles from the closed lane (see Algorithm 1, lines 15 to 23). These headway values are based on the findings in (Ren et al., 2020b).

Phase 5: EV Leaves the Work Zone

Once the EV has successfully passed through the work zone, the algorithm restores the traffic management system to its default state, and the NEM instructions are resumed for all vehicles in the work zone (see Algorithm 1, lines 28 to 31).

4 EVALUATION

4.1 Simulation Settings

The algorithm was implemented using the Simulation of Urban MObility (SUMO) traffic simulator, known for its flexibility and well-documented features. SUMO is an open-source software that includes the Traffic Control Interface (TraCI) package, allowing for time headway and speed limit adjustments. The simulated network covers 2,000 meters before the work zone, followed by 400 meters of the work zone itself and an additional 400 meters after the work zone. The study focuses on a two-lane highway with the right lane closed due to a work zone. Each simulation run lasts for an hour in real time and is repeated 20 times with different random seeds for consistency. The traffic composition includes 3% heavy vehicles, 96% passenger cars, and 1% EVs.

4.2 Scenarios and Evaluation Metrics

To assess the effectiveness of the ADAPT-EMERG algorithm, its results are compared with NEM (Ren et al., 2020b) in different scenarios with varying levels

Algorithm 1: Adaptive Traffic Management for Emergency Vehicles in Work Zones (ADAPT-EMERG).

```
Data: vehs, EV_present, edge_vehicle_classes
Result: EV_on_lane
foreach vehicle veh in vehs do
    if EV_present then
        (x, y) ← getPosition(veh);
        if x < metering zone and vehicleClass = "emergency" then
            changeVehicleLane ← openLane;
        else
            if x ∈ metering zones and vehicleClass = "emergency"
              then
                laneID ← getLaneID(veh);
                if laneID = "openLane" then
                    setLaneMaxSpeed("openLane") ← 30;
                    setLaneMaxSpeed("closedLane") ← 10;
                else
                    setLaneMaxSpeed ← 20;
            else
                if x ∈ merging zone and vehicleClass =
                  "emergency" then
                    laneID ← getLaneID(veh);
                    if laneID = "closedLane" then
                        vehiclesInLane ←
                          getLastStepVehicleIDs("openLane");
                        foreach V in vehiclesInLane do
                            if vehicleClass ≠ "emergency"
                              then
                                setVehicleHeadway ←
                                  3.9;
                            else
                                setVehicleHeadway ←
                                  1.7;
                    else
                        Apply NEM approach
                else
                    Apply NEM approach
    else
        Apply NEM approach;
        setLaneMaxSpeed(openLane) ← 20;
        setLaneMaxSpeed(closedLane) ← 20;
```

of traffic. The scenarios in Table 2 are based on the number of vehicles that entered the network within one hour.

Table 2: Scenarios and Vehicle Input.

Scenario	Vehicle Input (vph)
Medium	1,200
Congested	1,600
Oversaturated	2,000

The strategies are evaluated based on the evaluation metrics described below:

- **Throughput:** This indicates the number of vehicles that have successfully reached their destination.
- **Average Waiting Time (AWT):** AWT records the average waiting time for all vehicles that have been inserted.
- **Average Travel Time (ATT):** ATT shows the average travel time for all vehicles that exited the simulation.

$$\text{Average Travel Time} = \frac{\text{Lane Length}}{\text{Average Speed}} \quad (10)$$

- **Average Time Loss (ATL) of EVs:** ATL shows the time lost by EVs from driving below the optimal speed. This includes slowdowns from intersections but excludes scheduled stops.
- **Average Depart Delay (ADD) of EVs:** ADD records the average waiting time for EVs that need to be inserted in the network but cannot do so due to insufficient road space.
- **EV Count:** This records the number of EVs that finished their trips.
- **Max Time Loss of EVs:** This records the maximum time loss of all EVs.

5 RESULTS AND DISCUSSION

The effectiveness of the ADAPT-EMERG algorithm was evaluated through a series of simulations under three different traffic scenarios in terms of the congestion level of the highway: Medium, Congested, and Oversaturated scenarios. The performance of this algorithm was recorded from 20 simulation runs using random seeds, and the reported values represent the averages of these runs. The overall performance of all control strategies is presented in Table 3. Also, the percentage difference compared to the baseline is provided in parentheses.

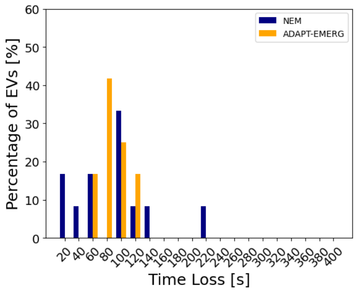
Table 3: Comparison of NEM Strategy and ADAPT-EMERG.

Metrics	Scenario: Medium	
	NEM	ADAP-EMERG
Throughput	1055	1145.85 (9%)
Average Waiting Time (AWT)	1.032	1.004 (3%)
Average Travel Time (ATT)	361.715	**158.9955 (56%)**
Average Time Loss (ATL) of EVs	87.5645	77.221 (12%)
Average Depart Delay (ADD) of EVs	4.4745	4.5045 (1%)
EV Count	11.85	12 (1%)
Max Time Loss of EVs	174.078	**103.1385 (41%)**
	Scenario: Congested	
Throughput	1397.4	1486.3 (7%)
Average Waiting Time (AWT)	33.5395	**3.93 (88%)**
Average Travel Time (ATT)	352.8105	**231.418 (34%)**
Average Time Loss (ATL) of EVs	171.63	165.6715 (3%)
Average Depart Delay (ADD) of EVs	28.493	**4.7165 (83%)**
EV Count	14.45	15.2 (5%)
Max Time Loss of EVs	322.0375	258.0475 (20%)
	Scenario: Over Saturated	
Throughput	1402.7	1493.75 (6%)
Average Waiting Time (AWT)	383.4785	341.991 (11%)
Average Travel Time (ATT)	351.9645	**248.007 (30%)**
Average Time Loss (ATL) of EVs	176.433	175.5235 (1%)
Average Depart Delay (ADD) of EVs	331.412	304.3585 (8%)
EV Count	14.5	15.3 (6%)
Max Time Loss of EVs	344.2225	292.2315 (15%)

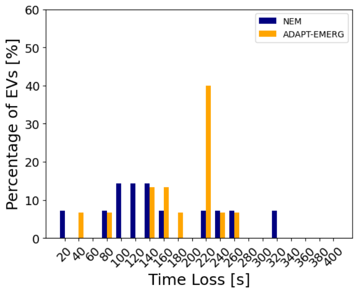
The ADAPT-EMERG algorithm consistently enhances **Throughput** in all scenarios, showing a nearly uniform percentage increase. This indicates its effectiveness in improving traffic flow and reducing congestion. This algorithm reduces **AWT** significantly, particularly in the congested scenario, indicating more efficient traffic management and reduced delays. The ADAPT-EMERG algorithm significantly reduces **ATT** in all scenarios, with the most substantial improvement seen in medium-traffic environments, followed by congested and oversaturated scenarios. It should be noted that for NEM, ATT decreases as traffic density increases because synchronized flow and effective coordination in certain density ranges enable smoother travel for many vehicles, reducing overall average travel time despite higher traffic volumes. Although the reduction in **ATL** for EVs in the oversaturated condition is marginal, the improvement is significant in medium scenarios. By increasing the speed limit for the lane with an emergency vehicle, other vehicles move faster, allowing EVs to travel at their optimal speed. This algorithm significantly reduces **Departure Delays** in almost full-capacity situations, proving its effectiveness in improving EV response times under moderate to high traffic conditions. By decreasing the departure delay of vehicles, this approach accommodates more EVs in all scenarios, especially in congested and oversaturated environments, indicating better accommodation of emergency traffic. **Maximum Time Loss for EVs** is significantly reduced, particularly in the medium-traffic scenario. Although the reduction is less marked in congested scenarios, it is still considerable, suggesting improved traffic management for EVs. The ADAPT-EMERG algorithm outperforms the NEM in all evaluated metrics and scenarios. The most notable improvements are observed in throughput, AWT, and ATT, especially under congested and oversaturated conditions. This demonstrates the superior capability of the ADAPT-EMERG algorithm in handling varying traffic densities, leading to enhanced traffic efficiency and reduced delays. However, despite substantial improvements in most metrics, the ADAPT-EMERG algorithm has a minor impact on the ATL of EVs in the oversaturated condition, suggesting a potential area for further optimization. Additionally, the improvement in AWT and ADD for medium traffic is not significant, because vehicles in such conditions already depart and move smoothly without delay due to the lack of congestion and obstacles.

Time Loss of Emergency Vehicles: In Figure 5, the analysis of time loss for EVs is presented under three scenarios. The comparison is made between the NEM and ADAPT-EMERG algorithms. In the medium scenario (Figure 5a), the ADAPT-EMERG algorithm shows its efficiency by significantly reducing time loss for EVs. While 42% of EVs using the NEM have a time loss under 60 seconds, compared to 17% for the ADAPT-EMERG algorithm. In the ADAPT-EMERG algorithm, no EV has a time loss of over 120 seconds. In contrast, 17% of EVs using the NEM face a time loss above this limit. In the congested scenario (Figure 5b), both approaches perform similarly regarding time loss below 60 seconds (7% for NEM and 7% for ADAPT-EMERG). However, the ADAPT-EMERG algorithm completely eliminates time loss above 260 seconds, whereas 14% of EVs using the NEM experience significant delays. Under over-saturated conditions (Figure 5c), the percentage of time loss below 60 seconds is similar for both approaches (7% for NEM and 7% for ADAPT-EMERG). However, the ADAPT-EMERG algorithm again shows a significant advantage by eliminating instances of time loss above 280 seconds, whereas the NEM results in 7% of cases with severe delays. Overall, the ADAPT-EMERG algorithm demonstrates better performance in minimizing time loss for EVs across all scenarios. This analysis highlights ADAPT-EMERG's capability to manage time loss more effectively, ensuring faster and more predictable travel times for emergency responders.

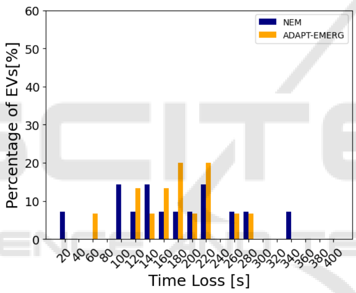
Travel Time of EVs: Figure 6 compares the trip durations of EVs under three different traffic scenarios using different approaches. In the medium scenario (Figure 6a), the NEM has an average trip duration of 204.67 seconds, while the ADAPT-EMERG algorithm has a significantly lower average trip duration of 146.75 seconds. The maximum trip duration for the NEM is 335.0 seconds, compared to 182.0 seconds for the ADAPT-EMERG algorithm. The ADAPT-EMERG algorithm outperforms the NEM with an average trip duration of approximately 28% shorter and a notable reduction in maximum trip duration. In the congested scenario (Figure 6b), the average travel time for the NEM is 287.64 seconds, whereas the ADAPT-EMERG algorithm achieves an average trip duration of 241.87 seconds. The maximum trip duration for the NEM is 568.0 seconds, compared to 318.0 seconds for the ADAPT-EMERG algorithm. The ADAPT-EMERG algorithm demonstrates superiority with an average trip duration roughly 16% shorter and a considerably lower maximum trip duration. In the over saturated scenario (Figure 6c), the average trip duration for the NEM is 290.14 seconds, while the ADAPT-EMERG algorithm records an average trip duration of 239.87 seconds. The maximum trip duration for the NEM is 452.0 seconds, in contrast to 332.0 seconds for the ADAPT-EMERG algorithm. Even in congested conditions, the ADAPT-EMERG algorithm maintains a shorter average trip duration by about 17%, and the



(a) Medium scenario

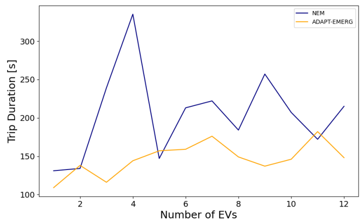


(b) Congested scenario

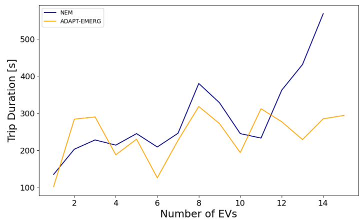


(c) Over saturated scenario

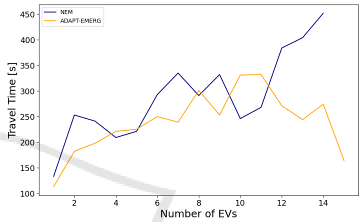
Figure 5: Distribution of time loss of EVs.



(a) Medium scenario



(b) Congested scenario



(c) Over saturated scenario

Figure 6: Trip duration of EVs in NEM and ADAPT-EMERG approaches.

maximum trip duration remains lower than the NEM. Across all scenarios, the ADAPT-EMERG algorithm consistently results in shorter average and maximum trip durations compared to the NEM.

6 CONCLUSION AND FUTURE WORKS

Given the aging infrastructure and the anticipated increase in highway work zones, enhancing work zone mobility and safety is crucial. Data shows improper merging maneuvers significantly contribute to highway work zone accidents, leading to severe congestion and delays. A previous study introduced the New England Merge (NEM) strategy, which requires vehicles to cooperate and create safe merging gaps when approaching lane closures in work zones. However, the performance of Emergency Vehicles (EVs) under this strategy was not explored. This research introduces Adaptive Traffic Management for Emergency Vehicles in Work Zones (ADAPT-EMERG) that modifies the NEM strategy when an EV is approaching, integrating merging techniques, headway spacing, and Variable Speed Limit (VSL) rules. The results demonstrate that this algorithm significantly enhances EV efficiency, reducing travel time and improving overall safety and mobility in highway work zones. The ADAPT-EMERG algorithm consistently proves to be a more efficient and reliable traffic management strategy compared to the NEM. It results in lower average travel times, reduces time loss for EVs, and shortens trip durations across various traffic scenarios. These findings suggest that implementing the ADAPT-EMERG algorithm can significantly improve traffic flow and EVs' response times, making it a superior choice for modern traffic management systems. Future research should evaluate the performance of other vehicle types in work zones and consider additional rules based on vehicle properties, such as size. Developing an algorithm that optimizes performance while considering the needs of all road users will be essential for comprehensive traffic management solutions.

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