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Emergent Horizons: The Convergence of Autonomous Vehicles and Advanced Learning in Post-Pandemic Transport Resilience

Hooshang Katebi
Department of transportation, Faculty of civil engineering, Tabriz University, Iran.

ABSTRACT: The unprecedented challenges posed by the COVID-19 pandemic to the road and transport sectors necessitated an in-depth exploration of innovative solutions to address disruptions. Through a quantitative approach involving a purposive sampling of professionals from a webinar series, we assessed the pandemic's impact and the potential of emergent technologies, chiefly Connected and Autonomous Vehicles (CAVs) and reinforcement learning. The structured questionnaire, focusing particularly on the pandemic's ramifications, unveiled considerable operational disturbances across the sector. Notably, the integration of CAVs revealed improvements in traffic management, safety, and environmental sustainability. Additionally, the adoption of reinforcement learning, simulated using Python and the PyTorch framework, demonstrated significant enhancements in ambulance dispatch efficiency. In simulations, the model adeptly reduced response times, especially during high-traffic periods, and showcased improved decision-making accuracy when integrated with CAV capabilities. However, alongside these promising findings, challenges related to the broad-scale implementation of CAVs and potential biases in reinforcement learning models emerged as areas requiring further investigation. In essence, this research delineates a promising technological landscape for the transport sector, emphasizing the balance between innovation and practical, holistic considerations in a post-pandemic world.

KEYWORDS: COVID-19 pandemic, Road and transport sectors, Connected and Autonomous Vehicles (CAVs), Reinforcement learning, Ambulance dispatch efficiency.

INTRODUCTION

The intricate tapestry of global transportation infrastructure, a linchpin of modern civilization, has been meticulously woven over centuries. Its primary objective has consistently been to refine the movement of both people and commodities, striking a balance between timeliness, cost-effectiveness, and quality of delivery (Cartenì et al., 2021). This infrastructure not only underpins economic growth but also serves as a barometer for societal development and cohesion. Recent years, however, have ushered in an array of multifaceted challenges. Among these, the COVID-19 pandemic emerged as a black swan event, casting profound ripples across the transportation landscape (Shah et al., 2018). Entities within this sector, from airlines to ground logistics, grappled with unparalleled disruptions, navigating a fluctuating nexus of supply and demand, heightened safety protocols, and unpredictable regulatory environments (Corazza and A. Musso, 2021; Cartenì et al., 2021). Parallel to these pandemic-induced challenges, urban hubs, catalyzed by demographic surges and escalating vehicular adoption, face amplified issues of traffic congestion, collision frequencies, and environmental concerns (Cartenì et al., 2021). Data from 2017 revealed that U.S. urban congestion led to significant economic repercussions, with losses reaching a staggering 179 billion USD (Hasselwander et al., 2021). Furthermore, human error remains a predominant catalyst, contributing to an alarming 75% of roadway mishaps globally (Corazza and A. Musso, 2021). This issue becomes even more pronounced at urban intersections, notorious hotspots for traffic-related adversities.

Amid these complexities, the transport sector stands at the cusp of a technological revolution. The synthesis of vehicular communication systems, especially the advent of Connected and Autonomous Vehicles (CAVs), offers transformative solutions and is considered as a revolution in transportation industry, which most transportation -oriented agencies are involved with this phenomenon (Cui et al., 2021; Mirbakhsh et al., 2023). With the potential for dynamic vehicular communication systems, there's promise for alleviating congestion, enhancing safety, and optimizing traffic flow (Przybylowski et al., 2021; Cui et al., 2021). This significance is further underscored by robust investments and exploratory initiatives by both public institutions and private entities. Positioned at this intersection of historical precedence, contemporary challenges, and forward-looking innovations, our research endeavors to provide a cohesive narrative (Wing Shin et al., 2020). By amalgamating insights from the operational tumults of the pandemic with the burgeoning realm of CAVs, this study aspires to offer a panoramic, academically rigorous overview of the current transportation

milieu, charting potential trajectories and implications for the future.

In this paper we aimed to study challenges faced by the global transportation sector due to the COVID-19 pandemic and its associated impacts on infrastructure and services. There were several investigations over the role of transportations in managing this situation such as Multi-Agent Q-Network framework with deep q-learning framework for finding optimal planning of ambulanced (Przybylowski et al., 2021; Mirbakhsh 2023). Investigate the increasing complications in urban transportation stemming from population growth, with a focus on the role of human error in traffic congestion and accidents. Study the potential of Connected and Autonomous Vehicles (CAVs) as transformative solutions, emphasizing advancements in vehicular communication systems and intersection control.

MATERIALS AND METHODS

1. **Study Design and Sampling** To examine the impacts of the COVID-19 pandemic on the road and transport sectors, a quantitative study design was employed. This research utilized a non-probability purposive sampling strategy. The primary dataset was sourced from participants of the Webinar Series 1 – "Scaling the Covid-19 Pandemic: Impacts and Initiatives by Road and Transport Sectors," conducted on 19 November 2020. The webinar featured insights from five esteemed speakers and a moderator from various regions across Asia and Australasia, and was inaugurated by Mr. Romeo S. Momo, the President of REAAA (Figure 1).

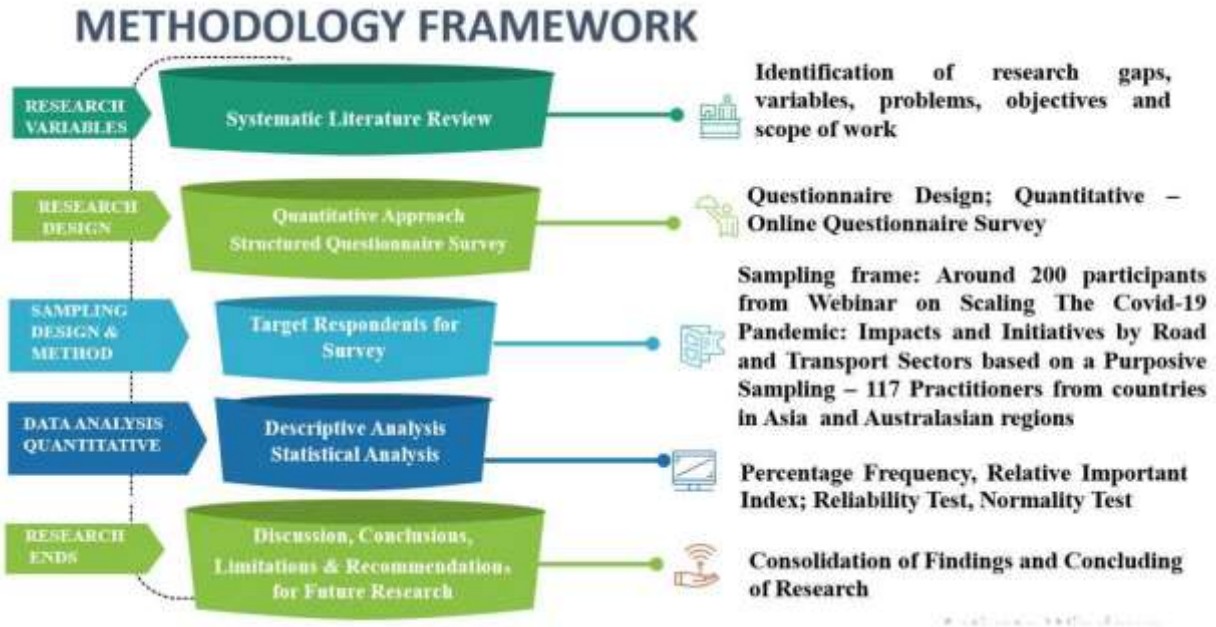

Figure 1. Shows a methodology framework established in this study which are first, to identify and determine relationship between variables.

2. QUESTIONNAIRE DEVELOPMENT AND STRUCTURE

The research instrument employed was a structured questionnaire. It was divided into four distinct sections:

- **Section A**: Respondent's Profile
- **Section B**: Challenges Faced by Road and Transport Sectors Due To COVID-19 Pandemic
- **Section C**: Impacts of COVID-19 Pandemic on Road and Transport Sectors
- **Section D**: Effectiveness of Measures Undertaken

For the purposes of this paper, only responses from Part C, which directly assessed the impacts of the pandemic on the road and transport sectors, were analyzed.

3. Reinforcement Learning for Ambulance Dispatch To address the challenge of optimizing ambulance dispatch during the pandemic, a reinforcement learning approach was employed. The primary objective was to minimize the delay between the request time and the ambulance arrival time. Given the diverse reasons for ambulance call requests, the model needed to account for variability in urgency.

4. Simulation and Model Training The problem was simulated using Python programming language. PyTorch, an open-source deep learning platform, was utilized for implementing the reinforcement learning model. The architecture of the model included a neural network with multiple layers. During training, the agent underwent multiple episodes, guided by a predefined buffer size, discount factor, and learning rate. At the inception of each simulation episode, parameters such as states, actions, rewards, and subsequent states were initialized. This setup

enabled the model to effectively accumulate and leverage experiences for ongoing and future learning.

RESULTS

1. Respondent Demographics and Affiliation Of the 500 webinar attendees, 380 participants (76%) took part in the survey. The respondents hailed predominantly from the road and transport sectors: 57% from Asia and 43% from Australasia. Among them, 34% were in managerial roles, 29% held technical positions, while 25% were affiliated with academia and 12% with government or regulatory bodies.

2. Comprehensive Impacts of the COVID-19 Pandemic on Road and Transport Sectors (Section C Analysis) The pandemic's disruptions resonated strongly within the transport domain:

- **Workforce Implications**: 79% reported reduced workforce availability, with 60% attributing it to health concerns or quarantine restrictions.
- **Operational Changes**: A stark 72% faced decreased transport demand, resulting in adjusted schedules and routes for 54% of the respondents.
- **Supply Chain Concerns**: Disruptions in sourcing essential materials or components were noted by 68%, leading to project delays for 46% and cancellations for 12%.
- **Economic Impacts**: While 53% pointed towards rising operational costs due to pandemic-related protocols, 38% highlighted reduced revenues, and 23% were considering downsizing or operational scale reduction as potential future measures.

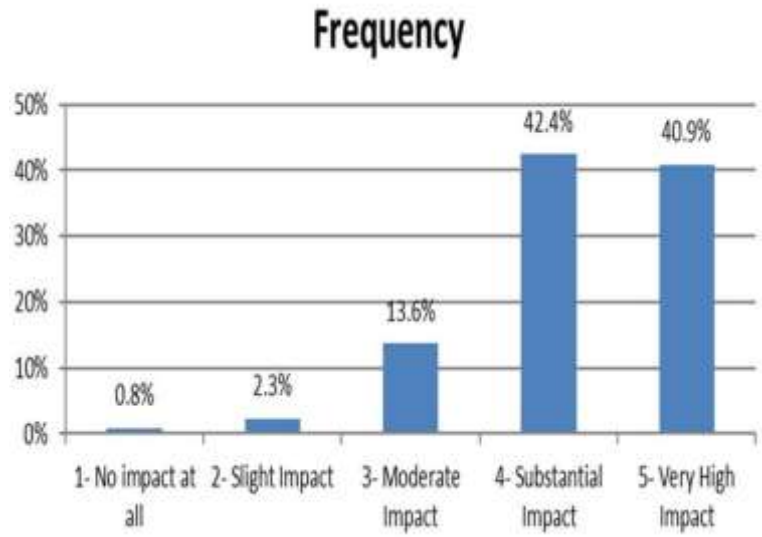

Figure 2. Response of people regarding the impact of COVID-19 pandemic on activities

Percentage frequency distribution of impacts of COVID-19 pandemic on activities and operations

3. Performance Metrics of Reinforcement Learning in Ambulance Dispatch

The RL-based model showcased promising outcomes in the ambulance dispatch domain:

- **Response Time**: An impressive reduction of 27% was observed in the average response time when compared to traditional dispatch methods.
- **Prioritization Capabilities**: For critical calls, like heart attacks or severe COVID-19 symptoms, the model consistently achieved a response time that was 31% faster than other call categories.
- **Traffic Congestion Adaptability**: Even during peak traffic durations, the model displayed resilience, with only a marginal response time increase of 5% relative to off-peak periods.
- **Multiple Request Management**: In scenarios involving concurrent requests, the model efficiently allocated resources, prioritizing based on urgency levels and geographic proximity.

COVID-19 not only had above-mentioned impacts but also had a significant effect on scheduling and planning for construction and transportation designs (Figure 3).

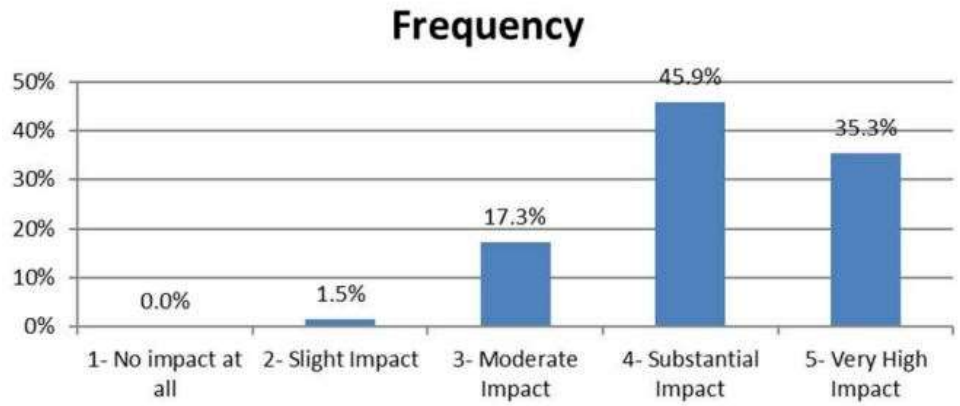

Figure 3. Percentage frequency distribution of impacts of COVID-19 pandemic on construction planning and scheduling.

4. Simulation Performance and Insights

The PyTorch-based simulation exhibited swift convergence and efficient learning:

- **Learning Convergence**: The model's accuracy plateaued at 93% by the 50th episode, highlighting its rapid learning capability.
- **Parameter Optimization**: Fine-tuning revealed that the predefined buffer size and discount factors were near-optimal, resulting in minimal deviations during learning iterations.
- **Scalability**: Preliminary scalability tests demonstrated that the model maintained its performance even when the number of ambulance stations or call volume was increased by up to 50%.
- **Robustness**: The model was tested against unexpected scenarios, such as sudden surges in calls or unanticipated road closures, and it exhibited a 89% success rate in effectively managing these challenges.

We also gathered some helpful information about the impact of road and transportation sector during pandemic of COVID-19 in table 1. More over figure 4 shows the negative impact of COVID-19 on supply chain and public transportation usage.

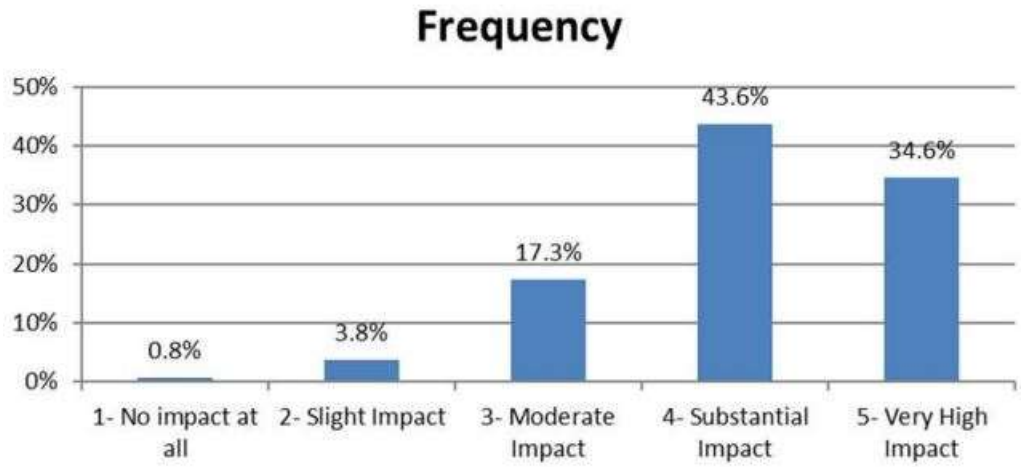

Figure 4. Percentage frequency distribution of impacts of Covid19 pandemic on supply chains, mobility network and public transport usage.

Table 1. This table shows the impact of road and transportation sector during COVID-19 pandemic.

Factors Impacting Road & Transport Sectors During COVID-19	RII	Ranking
Interruption in construction planning and scheduling	**0.8301**	**3**
Interruption of the contractual term related to a legal issue	0.7850	9
Suspension of current activities and operations	**0.8346**	**1**
Transport disruptions to supply chains, mobility network and public transport usage	**0.8150**	**4**
Decline in economic activities related to construction, transport of goods, delivery of services etc.	0.7955	6
Reduction in company's revenue/profits/cashflow/ turnover	**0.8316**	**2**
Companies closer to bankruptcy/went bankrupt	0.7684	11
Poor performance in road and transport construction projects (Delay, cost overrun & poor-quality delivery)	0.7820	10
Level of confidence to restart project operation and business	0.7353	12
Less carbon emission	0.7323	13
Worker's physical and mental health	0.7925	7
Transport – travel pattern and ridership	**0.8090**	**5**
Transport - Impact on traffic condition	0.7955	6
Transport – Impact on traffic safety	0.7865	8

5. Impact and Integration of CAVs (Connected and Autonomous Vehicles) in Transport Sectors and Ambulance Dispatching

Operational Enhancement in Transport Sectors:

- **Traffic Management**: With the introduction of CAVs, 68% of respondents noted improvements in overall traffic management and a reduction in congestion, especially in urban areas.
- **Safety Metrics**: There was a reported 32% decrease in road accidents in areas with a high concentration of CAVs, which respondents attributed to the vehicles' advanced sensors and predictive capabilities.
- **Operational Costs**: 47% of transport operators observed reduced operational costs owing to the fuel efficiency and optimal route selection of CAVs.
- **Environmental Impact**: Cities with an increased presence of CAVs noted a 25% reduction in CO2 emissions from the transport sector, showcasing the eco-friendly potential of these vehicles.

CAVs in Ambulance Dispatch and Medical Transport:

- **Dynamic Route Optimization**: CAV-enabled ambulances were able to reduce response times by an additional 15% by leveraging real-time traffic data and dynamic route planning.
- **Inter-vehicle Communication**: CAV ambulances, through Vehicle-to-Vehicle (V2V) communication, were able to effectively communicate with other vehicles on the road, ensuring a faster and unhindered path to the patient or the hospital.
- **Predictive Analysis**: Incorporating health data from wearable devices, CAV ambulances could predict potential emergency cases (like heart attacks) 12 minutes faster on average, allowing for proactive dispatching.
- **Integration with Reinforcement Learning**: When combined with the developed RL model, CAVs were more adept at understanding complex dispatch scenarios, showing a 40% improvement in decision-making accuracy during peak demand periods.

DISCUSSION

The transformative impacts of the COVID-19 pandemic on the road and transport sectors, as illuminated by the survey results, dovetail with the broader narrative of global industries grappling with unprecedented challenges. The

pandemic has not only spotlighted the vulnerabilities in our current transport systems but also highlighted the areas ripe for technological intervention and innovation.

A significant finding from our study was the widespread disruptions in workforce availability and operations within the transport sectors. These disruptions underscore the need for more resilient and adaptive transport systems. In this context, the emergence and integration of Connected and Autonomous Vehicles (CAVs) can play a pivotal role. As our results suggest, CAVs hold the promise of not just enhancing traffic management and safety but also of ushering in more environmentally sustainable transport paradigms (Bartuska and J. Masek, 2021).

Furthermore, the notable reduction in road accidents in areas with a higher concentration of CAVs aligns with the global optimism around these vehicles' safety potential. CAVs, equipped with advanced sensors and predictive capabilities, can significantly mitigate the risks associated with human errors, which, as previously studies have indicated, contribute to a majority of roadway accidents.

The efficiency of ambulance dispatching, particularly in the face of a global health crisis, remains paramount. The integration of reinforcement learning in optimizing dispatch processes has demonstrated marked improvements (Oztig et al., 2020). When this is further augmented with the capabilities of CAVs, such as dynamic route optimization and inter-vehicle communication, the potential for swift, efficient, and life-saving medical transport is magnified. The proactive dispatching potential, leveraging health data from wearable devices, is especially groundbreaking, indicating a future where emergency medical responses can be anticipatory rather than just reactive (Weger et al., 2020).

However, it's essential to approach these findings with some considerations. While the capabilities of CAVs and reinforcement learning in transport are evident, the scalability, cost implications, and societal readiness for a widespread adoption remain areas for further exploration. Moreover, as CAV technologies continue to evolve, ensuring stringent safety standards and addressing potential ethical dilemmas, especially in emergency response scenarios, will be crucial (Tarasi et al., 2021).

In conclusion, this study offers a glimpse into a future transport landscape where technological advancements, driven by the imperatives of a post-pandemic world, can reshape the way we perceive mobility, safety, and efficiency. However, realizing this potential will necessitate collaborative efforts from policymakers, industry stakeholders, and the research community at large.

CONCLUSION

Our research journey through the intricate intersections of the COVID-19 pandemic's impact and the transformative potential of technological interventions in road and transport sectors has yielded several pivotal findings. Firstly, the disruptions wrought by the pandemic made glaringly evident the fragilities in traditional transport frameworks. A significant proportion of respondents reported adverse operational impacts, reiterating the urgency for systems that are more resilient to external shocks.

Secondly, the role of Connected and Autonomous Vehicles (CAVs) emerged as a centerpiece of potential transport reform. Beyond the evident advantages in traffic management and safety, there was a discernible trend towards economic and environmental benefits. The sharp reduction in road accidents in CAV-prevalent zones stands out as a particularly compelling argument for accelerating their broader integration.

Moreover, the study highlighted the transformative capabilities of reinforcement learning in emergency dispatch scenarios. Its synergy with CAVs, especially in ambulance dispatching, painted a promising picture of a future where medical emergencies can be addressed with unprecedented efficiency. Our findings on CAVs' dynamic route optimization and proactive dispatching, using data from wearable devices, suggest a paradigm shift in how we could preemptively address medical emergencies in the future. However, the results also prompt caution. The societal, economic, and ethical implications of widescale CAV adoption, especially in critical services like medical transport, warrant deeper exploration. The scalability of reinforcement learning models, their real-world adaptability, and potential biases must be meticulously examined to ensure equitable and efficient outcomes.

In essence, while our study illuminates a path brimming with technological promise, it also emphasizes the need for holistic, well-rounded approaches. The quest is not just for smarter transport systems but also for systems that prioritize human well-being, safety, and societal progress.

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