Scientific Research Publishing

Journal of Biosciences and Medicines, 2026, 14(2), 362-382
https://www.scirp.org/journal/jbm
ISSN Online: 2327-509X
ISSN Print: 2327-5081

The Paradox of Pre-Crash Determinants: Analyzing the Disconnect between Ambulance Response Times and Traffic Fatality Rates in Saudi Arabia

Md. Mazharul Hoque

Emergency Medical Services Program/Department, College of Nursing and Health Sciences, Jazan University, Jazan, Saudi Arabia
Email: mazharulhaque@jazanu.edu.sa

How to cite this paper: Hoque, Md.M. (2026) The Paradox of Pre-Crash Determinants: Analyzing the Disconnect between Ambulance Response Times and Traffic Fatality Rates in Saudi Arabia. *Journal of Biosciences and Medicines*, **14**, 362-382.
https://doi.org/10.4236/jbm.2026.142027

Received: December 4, 2025
Accepted: February 8, 2026
Published: February 11, 2026

Abstract

This study investigates the paradoxical relationship between ambulance response times and traffic fatality rates across Saudi Arabia's 13 administrative regions in 2024. Contrary to conventional expectations of a positive correlation, the analysis reveals a weak to moderate *negative* association, indicating that faster emergency medical services (EMS) responses do not necessarily translate into lower mortality from road traffic collisions. The "Aseer-Tabuk Paradox" exemplifies this disconnect: regions with rapid ambulance responses (e.g., Aseer) recorded among the highest fatality rates, while slower-response regions (e.g., Tabuk) also exhibited elevated mortality. Instead, the findings underscore the dominant role of pre-crash determinants—such as road design, driver behavior, and accident severity—in shaping fatality outcomes. Additionally, a strong positive correlation was observed between investment in internal road safety infrastructure and faster *in-city* ambulance response times, highlighting infrastructure's dual function in accident prevention and emergency access facilitation. The study advocates for a holistic, two-pronged road safety strategy that equally prioritizes primary prevention (pre-crash interventions) and secondary response (post-crash care optimization). By shifting policy focus from EMS-centric approaches to integrated, regionally tailored measures, this research provides evidence-based insights for enhancing national traffic safety frameworks in Saudi Arabia and similar contexts.

Keywords

Road Traffic Fatalities, Ambulance Response Time, Pre-Crash Determinants, Emergency Medical Services (EMS), Traffic Safety Paradox, Saudi Arabia, Regional Disparities, Road Safety Infrastructure, Primary Prevention,

Secondary Prevention

1. Introduction

Road traffic injuries represent a critical global public health challenge, with significant social, economic, and healthcare burdens [1]. In Saudi Arabia, a nation characterized by rapid urbanization, extensive road networks, and diverse geographic landscapes, traffic safety remains a paramount concern for national development goals [2]. Traditional road safety models often emphasize the importance of rapid emergency medical services (EMS), particularly ambulance response times, as a key factor in reducing mortality following traffic collisions [3]. The underlying assumption is that longer response times directly correlate with higher fatality rates due to delays in providing life-saving care [4].

This study challenges that conventional hypothesis through a detailed analysis of regional-level data from Saudi Arabia for the year 2024. Contrary to expectations, our investigation reveals a weak to moderate *negative* correlation between ambulance response times and traffic fatality rates, both inside and outside urban centers. This counter-intuitive finding suggests that the relationship between EMS performance and traffic mortality is not straightforward but is significantly moderated, and perhaps overshadowed, by other pre-crash and contextual factors.

The analysis identifies stark regional disparities, exemplified by the "Aseer-Tabuk Paradox", where regions with some of the fastest ambulance responses also report the highest death rates. This underscores the potential dominance of factors such as road design, traffic law enforcement, driver behavior, and accident severity over post-crash care logistics in determining ultimate fatality outcomes [5]. Furthermore, the data reveals a strong positive correlation between investments in internal road safety infrastructure and faster *in-city* ambulance response times, highlighting the dual role of such infrastructure in both accident prevention and emergency response facilitation.

Figure 1 depicts the central paradox of the Saudi Arabian traffic fatality analysis by introducing a strong, counter-intuitive correlation (R = 0.74) between faster ambulance response times in urban areas and higher regional fatality rates. The graphic visually presents this unexpected relationship with the label "PARADOXICAL CORRELATION" prominently featured, suggesting that simply improving urban emergency medical logistics does not, in itself, guarantee lower death tolls. It highlights the case of the Tabuk Region as a specific example of this trend and frames this finding within the broader context of "REGIONAL HETEROGENEITY", implying that underlying factors—such as rural response delays, infrastructure, or driving behaviors—vary significantly across regions and critically influence overall traffic safety outcomes beyond urban emergency response capabilities.

The primary objective of this paper is to dissect this complex interplay and shift the policy discourse from a singular focus on EMS response optimization to a

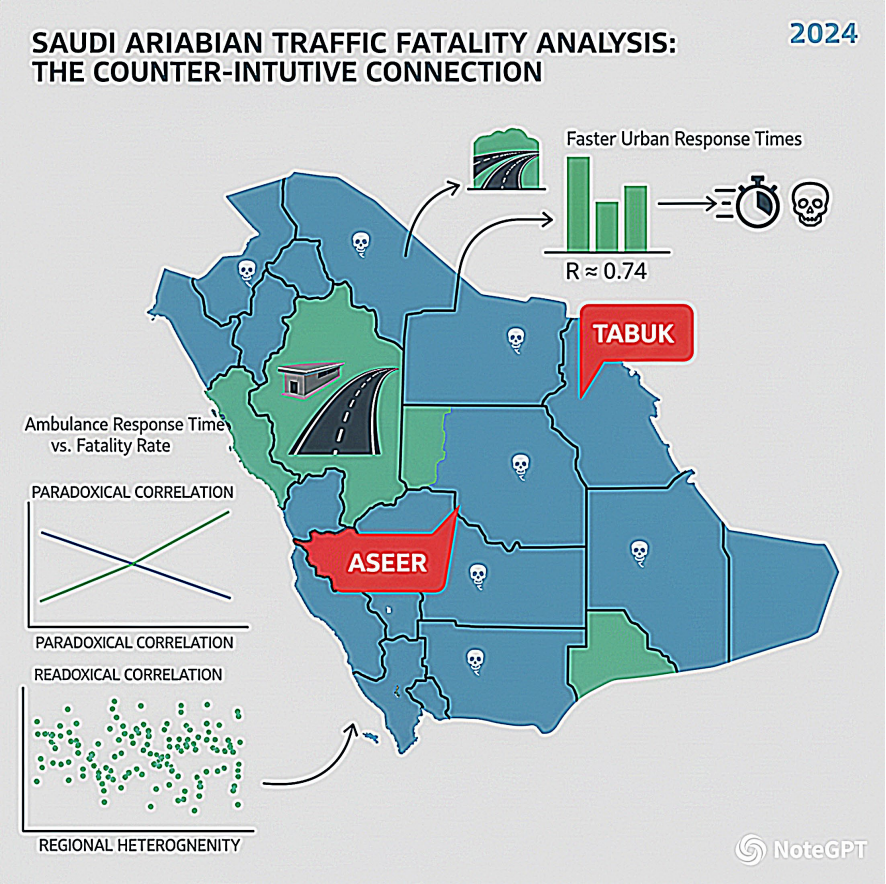

Figure 1. Saudi Arabian traffic fatality analysis: the counter-intuitive connection.

more holistic, two-pronged strategy that equally prioritizes primary prevention and secondary response. By doing so, this research aims to contribute evidence-based insights for designing more effective national road safety strategies in Saudi Arabia and similar contexts.

2. Review of Literature

The literature on road traffic fatalities has evolved from focusing on single factors to adopting integrated systems approaches, such as the Safe System model, which acknowledges the shared responsibility of road designers, vehicle manufacturers, and users.

2.1. The Role of Emergency Response Time

A substantial body of international research supports the "golden hour" concept, positing that rapid trauma care significantly improves survival odds [6]. Studies in various settings have found correlations between reduced EMS response times and lower mortality for time-sensitive conditions like cardiac arrest and major trauma. Consequently, EMS response time is a well-established Key Performance Indicator (KPI) in health systems worldwide, and much policy effort is dedicated to its improvement.

2.2. Limitations of the Response-Time Paradigm

However, recent scholarly work has begun to critique an over-reliance on response time as a sole metric. Research indicates that the *clinical capability* of first responders and the *severity of the initial injury* are often more critical determinants of survival than mere speed of arrival [7]. Furthermore, studies in rural and geographically challenging areas show that despite longer response times, fatality rates can be moderated by other factors, such as road safety campaigns or vehicle safety standards, highlighting the multifactorial nature of traffic mortality [8].

2.3. The Primacy of Primary Prevention

Epidemiological research consistently identifies pre-crash factors—including speeding, non-use of seatbelts and helmets, poor road design, and inadequate signage—as the principal determinants of both crash occurrence and severity [9]. The World Health Organization's (WHO) recommendations for road safety heavily emphasize legislation, enforcement, and infrastructural improvements (like traffic calming and dedicated pedestrian facilities) as the most effective interventions for saving lives [10]. The literature suggests that while efficient EMS is crucial, its impact is maximized when the number and severity of crashes are first reduced through preventive measures.

2.4. Infrastructure as an Enabler for Safety and Response

A growing area of study explores the dual function of road infrastructure. Well-designed roads not only prevent accidents but also facilitate smoother traffic flow, which directly benefits emergency vehicle access. Research has shown that features like emergency lanes, coordinated traffic signals, and road geometry improvements can substantially reduce EMS travel times within cities [11]. This aligns with the "whole journey" safety approach, integrating planning and design with emergency management.

2.5. Geographic and Contextual Disparities in Road Safety

Studies highlight that national averages often mask significant sub-national inequalities in road safety outcomes. Regional variations in terrain, population density, road quality, and enforcement capacity can lead to disparate fatality rates and EMS performance [12]. The Saudi context, with its unique combination of vast deserts, high-speed highways, and dense urban centers, presents a distinct case study for such disparities, which have been underexplored in the literature [13].

2.6. Gap in Literature

While the separate strands of EMS effectiveness and road safety prevention are well-documented, there is a scarcity of empirical, regionally-disaggregated studies that statistically examine the *relative weight* and potential *disconnect* between these factors in determining fatality rates, particularly in the Gulf Cooperation Council (GCC) context. This study addresses this gap by quantitatively analyzing

the non-intuitive relationship between ambulance response times and death rates across Saudi regions, thereby offering a nuanced perspective that can inform more targeted and effective policy interventions.

3. Materials and Methods

This study employs a quantitative, cross-sectional, and observational research design to analyze the relationship between ambulance response times, road safety infrastructure, and traffic fatality rates across the administrative regions of Saudi Arabia for the year 2024 [14]. The methodological framework is structured around data acquisition, variable definition, and statistical analysis.

3.1. Data Sources

The analysis is based on two primary, officially sanctioned data sources.

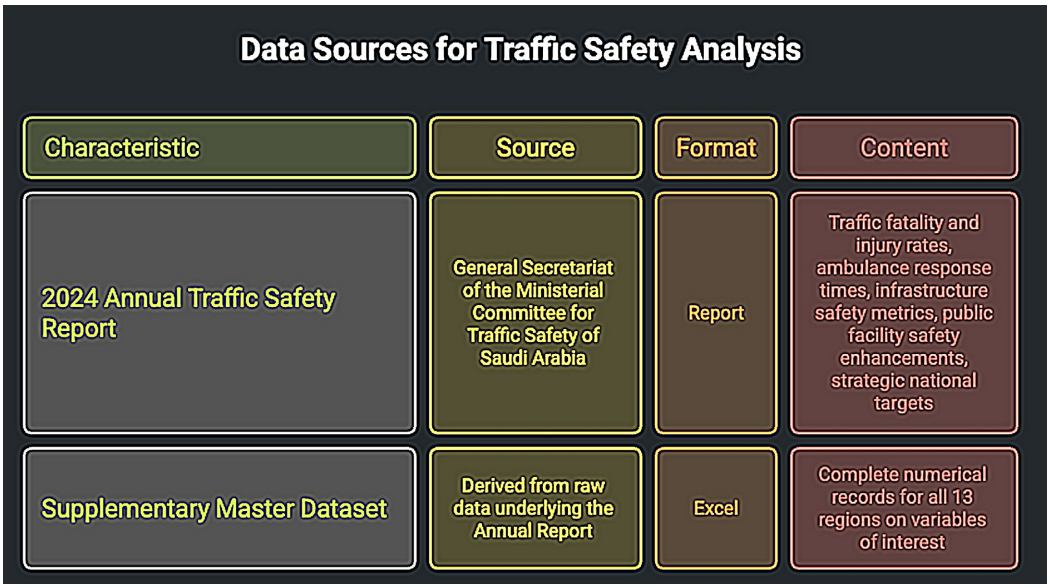

Figure 2. Overview of the primary data sources used in the analysis.

Figure 2 depicts a robust and hierarchical data foundation for the traffic safety analysis, centering on the authoritative 2024 Annual Traffic Safety Report published by the General Secretariat of the Ministerial Committee for Traffic Safety of Saudi Arabia. This primary report provides the official metrics on fatality and injury rates, ambulance response times, and strategic national safety targets. To enable granular regional analysis, this report is supplemented by a Supplementary Master Dataset in Excel format, which contains the complete, raw numerical records for all 13 regions, thereby allowing for the detailed cross-comparisons of specific variables like urban versus rural ambulance performance that are visualized in the subsequent findings.

1) The 2024 Annual Traffic Safety Report (Media Version): Published by the General Secretariat of the Ministerial Committee for Traffic Safety of Saudi Arabia, this report serves as the authoritative national record [15]. It provides consol-

idated, regionally disaggregated data on key performance indicators (KPIs), including:

- Traffic fatality and injury rates (per 100,000 population).
- Average ambulance response times (within cities and outside cities).
- Infrastructure safety metrics (e.g., length of internal road safety projects, completion rates of external road projects).
- Data on public facility safety enhancements (schools, mosques, health centers).
- Strategic national targets for 2024-2026.

2) Supplementary Master Dataset (Excel Format): A detailed dataset was constructed, likely derived from the raw data underlying the Annual Report. This dataset enabled precise statistical calculations and correlation analyses at the regional level. It contains the complete numerical records for all 13 regions of Saudi Arabia on the variables of interest.

3.2. Study Population and Unit of Analysis

The unit of analysis is the administrative region (*Mintaqah*) of Saudi Arabia. All 13 regions were included: Riyadh, Makkah, Madinah, Eastern, Al Qassim, Aseer, Hail, Tabuk, Al Baha, Northern Borders, Al Jouf, Jazan, and Najran. This regional-level analysis allows for the examination of geographic and infrastructural disparities within the national context.

3.3. Variable Definition and Operationalization

- **Primary Dependent Variable:**
  - **Traffic Fatality Rate:** Operationally defined as the number of deaths from traffic accidents per 100,000 population in each region for 2024.
  - **Injury Rate:** Operationally defined as the number of non-fatal injuries from traffic accidents per 100,000 population in each region for 2024. This metric was sourced from the same 2024 Annual Traffic Safety Report (Media Version) and the accompanying Supplementary Master Dataset, consistent with the fatality rate variable.
- **Primary Independent Variable:**
  - **Ambulance Response Time:** Measured in two contexts:
    - **Outside Cities:** Average response time (in minutes) to traffic accidents occurring outside urban boundaries.
    - **Within Cities:** Average response time (in minutes) to traffic accidents occurring within urban boundaries.
- **Moderating and Contextual Variables:**
  - **Road Safety Infrastructure Investment:** Quantified as the total length (in kilometers) of completed internal road projects meeting traffic safety standards in each region.
  - **Regional Characteristics:** Descriptive data on geography, population density, and external road project completion rates were used for qualitative interpretation of disparities.

3.4. Data Analysis

The analytical process consisted of descriptive, correlational, and interpretive steps:

1) Descriptive Statistics: For each region, key metrics (death rate, response times, infrastructure length) were tabulated. National and regional summaries were generated to highlight disparities (e.g., range and mean of response times).

2) Correlational Analysis: Pearson correlation coefficients (R) were calculated to assess the strength and direction of linear relationships between variables for the pooled regional data:

- Death Rate vs. Ambulance Response Time (Outside Cities).
- Death Rate vs. Ambulance Response Time (Within Cities).
- Length of Internal Road Safety Projects vs. Ambulance Response Time (Within Cities).

3) Comparative Case Analysis: Specific regions were selected as illustrative cases based on outlier status:

- **The "Aseer-Tabuk Paradox":** Aseer (low response time, high death rate) and Tabuk (high response time, very high death rate) were analyzed in depth to explore factors beyond response times.
- **Slow-Response Regions:** Riyadh, Madinah, and Tabuk were examined to identify common logistical and geographical challenges.

4) Benchmarking Against Targets: Regional performance for 2024 was compared against the national strategic targets for the same year (e.g., target ambulance response time of 11 minutes outside cities, death rate target of 13 per 100,000) to contextualize the findings within the national policy framework.

5) Interpretive Synthesis: Statistical findings were integrated with qualitative insights from the report (e.g., mentions of terrain challenges, enforcement campaigns, air ambulance use) to develop a nuanced understanding of the mechanisms influencing fatality rates. This synthesis moved beyond correlation to propose a conceptual model where pre-crash factors are primary determinants, and response time acts as a critical moderating variable.

Control for Confounding Variables: The reported correlation analyses are bivariate and do not control for potential confounding variables such as population density, traffic volume, or regional crash severity indices. While these factors are critical to a complete causal understanding, they were not consistently available in the aggregated regional datasets used for this study. The findings should therefore be interpreted as revealing associative patterns at the ecological (regional) level, highlighting the need for more granular, multi-variable data in future research.

3.5. Ethical Considerations and Limitations

- **Ethics:** This study utilized aggregated, anonymized, and publicly (or officially) reported data, posing no risk to individual privacy.
- **Limitations:**
  - The ecological study design (regional-level analysis) prevents inference of

causality at the individual accident level.

- The analysis is cross-sectional for a single year (2024). This design captures a snapshot of regional relationships but prevents the identification of temporal trends, causal sequences, or the assessment of whether the observed paradoxical patterns are stable over time or represent an anomaly for the study year. Longitudinal data spanning multiple years is needed to understand the dynamics of these associations and to evaluate the impact of policy changes.
- Data on potentially crucial confounding variables (e.g., average crash severity index per region, exact driver behavior metrics, detailed terrain data) were not available in the provided datasets, which is acknowledged as a constraint in the discussion.

4. Results and Observations

4.1. Executive Summary of Findings

This analysis reveals a complex and counter-intuitive relationship between ambulance response times and traffic fatality rates across Saudi Arabian regions in 2024 [15]. Contrary to conventional expectations, the data demonstrates no statistically significant positive correlation between extended response times and increased mortality following traffic collisions.

Figure 3 depicts significant regional disparities in ambulance response times and a notable inverse relationship with death rates across the Kingdom of Saudi

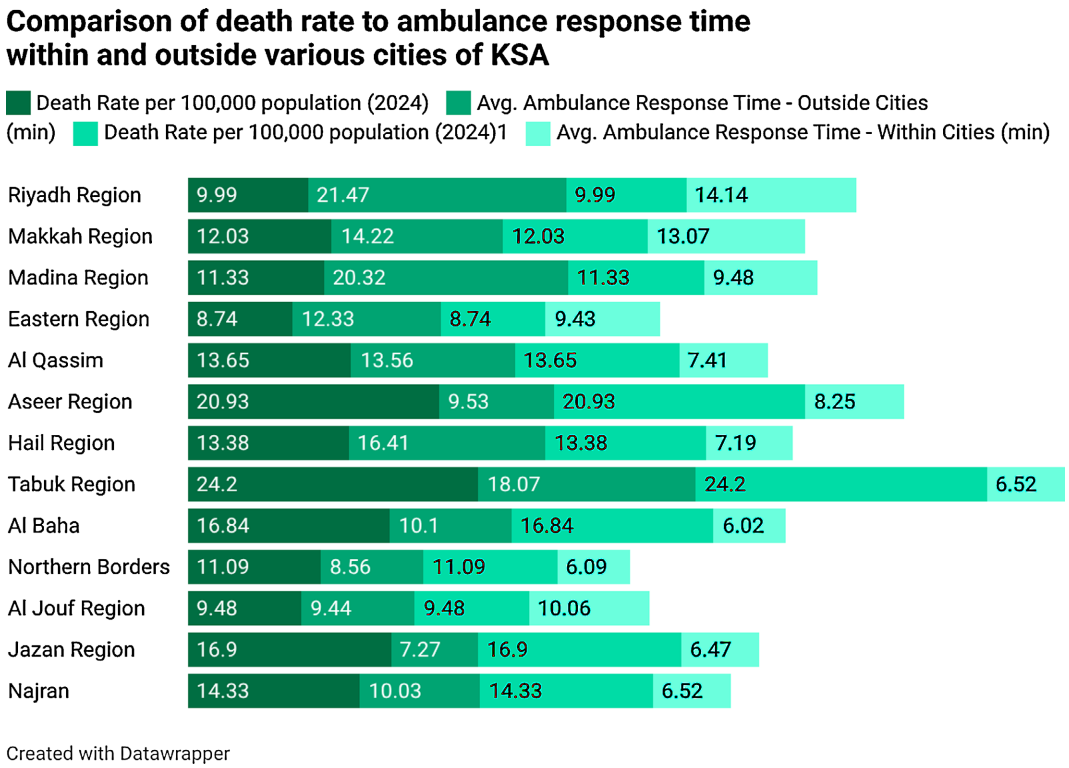

Figure 3. Regional data for 2024 on death rates and ambulance response times both inside and outside cities.

Arabia in 2024. While the death rate per 100,000 population remains constant for each region regardless of location, the data reveals that ambulance response times are consistently and substantially faster within cities compared to outside cities in almost every region. For instance, in the Tabuk Region, where the death rate is the highest at 24.2, the response time outside cities is a critical 18.07 minutes, but plummets to just 6.52 minutes within the urban center. This pattern suggests that geographic accessibility to emergency services is a major factor, as regions with the most challenging response times outside urban areas, like Tabuk, Aseer, and Riyadh, tend to correlate with higher overall death rates, highlighting a critical urban-rural divide in emergency healthcare logistics.

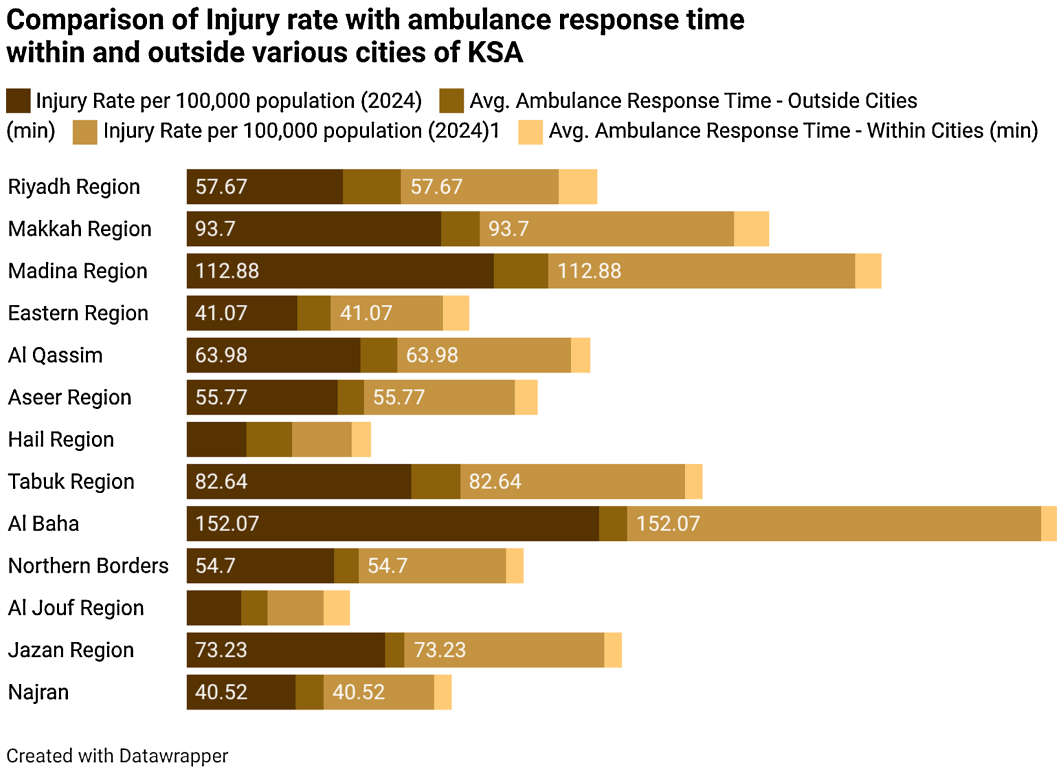

Figure 4. Regional data for 2024 on injury rates and corresponding ambulance response times outside cities.

Figure 4 depicts a distinct pattern where high injury rates in several regions coincide with critically long ambulance response times outside cities, underscoring a potential vulnerability in pre-hospital emergency care in rural or remote areas. The data shows that regions with the highest reported injury rates per 100,000 population—such as Al Baha (152.07), Madinah (112.88), and Makkah (93.7)—are also served by ambulances whose average response times outside urban centers are substantial, at 10.1, 9.48, and 14.22 minutes respectively. This correlation suggests that in areas where the frequency of traumatic events is elevated, the logistical challenge of reaching patients in geographically dispersed locations may exacerbate outcomes, highlighting a critical pressure point in the emergency medical services infrastructure for non-urban settings across the Kingdom.

4.2. Key Observations

1) Paradoxical Correlation Patterns: The anticipated positive relationship between longer ambulance response times and higher fatality rates is not substantiated by the regional data. Instead, weak-to-moderate negative correlations emerge, suggesting faster response systems may coexist with elevated death rates in certain contexts.

2) Regional Heterogeneity in EMS Performance: Substantial disparities exist in emergency response capabilities, particularly for incidents occurring outside urban centers. Response times for "Outside Cities" show remarkable variation, ranging from 7.27 to 21.47 minutes across different administrative regions.

3) The Aseer-Tabuk Paradox: A striking pattern emerges wherein regions with comparatively rapid ambulance response times—notably Aseer and Tabuk—nevertheless report among the highest traffic fatality rates nationally. This observation challenges the presumed primacy of post-crash medical intervention in determining mortality outcomes.

4) Infrastructure as Response Enabler: A strong positive correlation ($R \approx 0.74$) exists between regional investment in internal road safety projects and faster urban ambulance response times. This suggests that road network design and traffic management infrastructure may serve dual functions in both accident prevention and emergency response facilitation.

Figure 5 depicts a notable relationship between infrastructure investment and

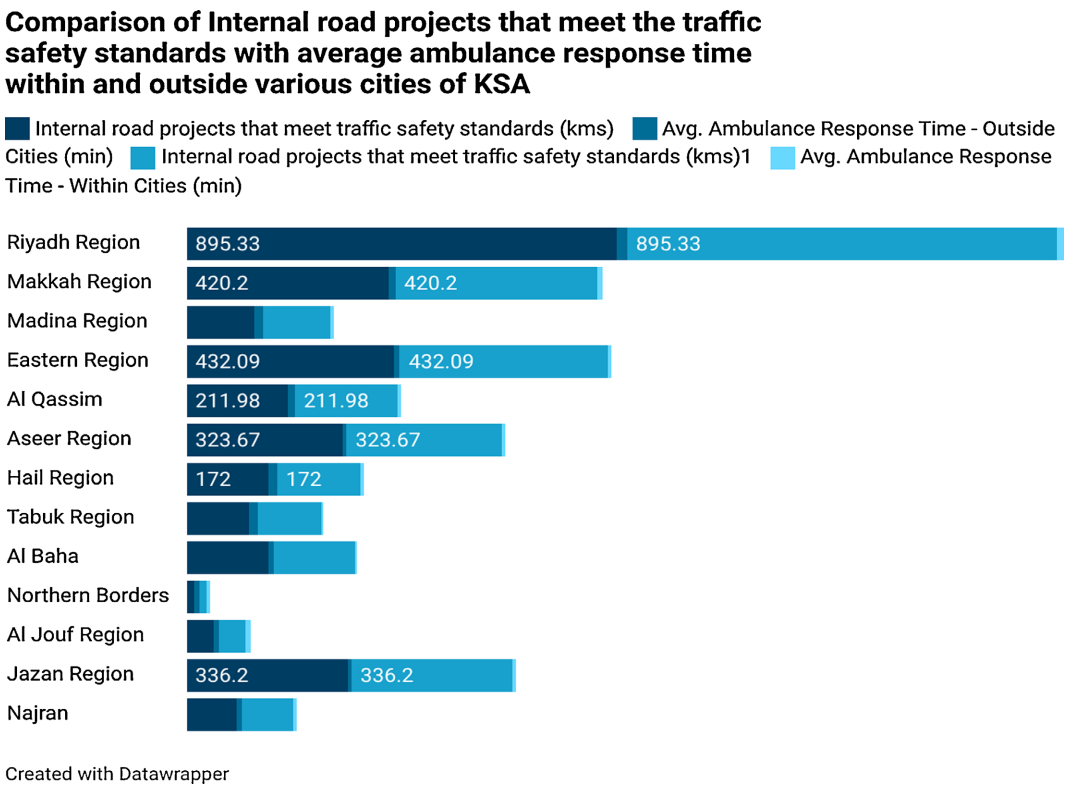

Figure 5. Comparison showing the correlation between the length of internal road safety projects and ambulance response times.

emergency service efficiency, revealing that regions with substantial lengths of internal road projects meeting traffic safety standards, such as Riyadh (895.33 km) and the Eastern Region (432.09 km), tend to exhibit significantly faster ambulance response times within their cities. The data suggests a correlation where enhanced, safety-compliant road networks in urban areas likely facilitate quicker navigation for emergency vehicles, contributing to reduced intra-city response times. Conversely, the absence of such projects in several regions, including Tabuk, Al Baha, and the Northern Borders, coincides with the previously noted longer response times outside cities, underscoring how strategic infrastructure development may be a key factor in improving not only road safety but also the critical performance metrics of emergency medical services across different geographic contexts in the Kingdom.

4.3. Detailed Statistical Analysis

4.3.1. Relationship Between Response Times and Fatality Rates

Table 1. Statistical correlation analysis.

Response Context	Correlation Coefficient (R)	Strength & Direction	p-value
Outside Cities	−0.094	Very weak negative	0.76
Within Cities	−0.505	Moderate negative	0.08

Interpretation of Table 1:

- The near-zero correlation for responses outside urban areas ($R \approx -0.09$, $p = 0.76$) indicates no statistically significant or meaningful linear relationship...
- The moderate negative correlation within urban settings ($R \approx -0.50$, $p = 0.08$) does not reach conventional statistical significance ($p < 0.05$) with $N = 13$ but suggests a notable associative pattern that contradicts the initial hypothesis...

4.3.2. Regional Disparities in Emergency Response Performance

Table 2. Extreme values in response times (outside cities).

Performance Category	Region	Response Time (minutes)	Corresponding Fatality Rate
Fastest Responders	Jazan	7.27	7.40
	Northern Borders	8.56	11.21
	Aseer	9.53	**20.93**
Slowest Responders	Riyadh	21.47	11.33
	Madina	20.32	11.33
	Tabuk	18.07	**24.20**

As shown in Table 2, contextual factors influencing Response Disparities are:

- **Geographical and Demographic Challenges:**

- High-population regions like Riyadh and the Eastern Province exhibit extended outside-city response times (21.47 and 12.33 minutes respectively), likely reflecting the logistical complexity of servicing vast metropolitan hinterlands with dispersed rural settlements.
- Makkah region contends with unique mobility challenges stemming from year-round pilgrim traffic, potentially impeding emergency vehicle movement both within and beyond urban precincts.

- **Infrastructure Density and Resource Allocation:**
  - Regions with dispersed populations (e.g., Northern Borders, Al Jouf) may achieve faster average response times through strategic placement of limited ambulance resources along critical transit corridors.
  - Urbanized regions with dense but congested road networks may experience delayed responses despite greater resource investment, particularly during peak traffic periods.

4.3.3. Case Analysis: High-Fatality Regions with Divergent Response Profiles

Tabuk Region Analysis:

- **Response Profile:** Slow outside-city response (18.07 minutes, third slowest nationally).
- **Fatality Outcome:** Highest national death rate (24.20 per 100,000).
- **Potential Explanatory Factors:** The combination suggests that factors preceding emergency response—including high-speed collision risk on long desert highways, limited immediate post-crash care, and potentially elevated accident severity—dominate mortality outcomes despite suboptimal EMS intervals.

Madina Region Analysis:

- **Response Profile:** Very slow outside-city response (20.32 minutes, second slowest nationally).
- **Fatality Outcome:** Mid-range death rate (11.33 per 100,000).
- **Potential Explanatory Factors:** The moderate fatality rate despite extended response times may indicate either: 1) effective post-crash care protocols that mitigate time delays, 2) lower baseline accident severity, or 3) successful primary prevention initiatives that reduce collision incidence or severity.

Aseer Region Analysis:

- **Response Profile:** Rapid outside-city response (9.53 minutes, third fastest nationally).
- **Fatality Outcome:** Second highest national death rate (20.93 per 100,000).
- **Interpretation:** This constitutes the clearest evidence of the "response time paradox", wherein efficient emergency medical services fail to translate into reduced mortality, strongly suggesting that pre-crash factors substantially outweigh post-crash intervention in determining final outcomes.

4.3.4. Infrastructure-Response Time Interdependence

Key Finding: A robust positive correlation ($R \approx 0.74$) emerges between regional

investment in internal road safety infrastructure projects and reduced in-city ambulance response times.

Implication: Road safety infrastructure—including traffic calming measures, emergency lane provisions, and optimized intersection design—appears to serve dual protective functions:

1) Primary Prevention: Reducing collision frequency and severity through improved road environments.

2) Secondary Facilitation: Enhancing emergency vehicle mobility and reducing time-to-scene intervals.

4.4. Synthesis and Strategic Implications

4.4.1. Reconceptualizing the Response Time-Fatality Relationship

The collected evidence necessitates a fundamental recalibration of conventional road safety models regarding emergency response:

1) Pre-Crash Factors as Primary Determinants: Accident frequency and severity—modulated by road engineering, traffic law enforcement, driver behavior, and vehicle safety standards—emerge as dominant predictors of mortality outcomes, potentially overshadowing post-crash medical response efficiency [16].

2) Response Time as Moderating Variable Rather Than Primary Driver: While not the principal determinant of fatality rates, ambulance response time functions as a critical moderating variable that interacts with baseline regional risk profiles [17]. In high-risk regions (e.g., Tabuk), improving suboptimal response times may yield substantial mortality reductions. In contrast, regions with already efficient EMS but elevated fatalities (e.g., Aseer) would benefit more from aggressive primary prevention strategies.

3) Infrastructure's Dual-Role Revelation: Road safety infrastructure investments demonstrate compound benefits, simultaneously reducing accident risk while enhancing emergency response efficacy [18]. This finding identifies a synergistic intervention point with multiplicative safety returns.

Table 3 provides a strategic, typology-based framework for addressing traffic fatalities by categorizing regions into three distinct profiles based on their fatality rates and ambulance response times. For High Fatality, Fast Response regions like Aseer, where efficient emergency medical services (EMS) are paradoxically paired with high death tolls, the primary challenge is severe accident occurrence, and thus interventions focus on prevention through enhanced road engineering, targeted enforcement, and awareness campaigns. Conversely, High Fatality, Slow Response regions like Tabuk face a crisis of geographic inaccessibility, making the recommended priorities revolve around overcoming logistical barriers through predictive ambulance deployment, air ambulance expansion, and infrastructure to improve emergency access. For Moderate Fatality, Slow Response regions like Madina, the challenge centers on operational EMS efficiency; here, the interventions are tactical, aiming to optimize dispatch systems and dynamically allocate existing resources to reduce response times, building on the proven link between

infrastructure and improved urban EMS performance.

Table 3. Regionalized strategic recommendations.

Region Type	Primary Challenge	Recommended Priority Interventions
High Fatality, Fast Response (Aseer-type)	Severe accidents despite efficient EMS	1. Enhanced road engineering in high-risk corridors 2. Targeted traffic law enforcement 3. Public awareness campaigns addressing regional risk factors 4. Investigation of accident severity determinants
High Fatality, Slow Response (Tabuk-type)	Geographic barriers to timely emergency care	1. Strategic ambulance deployment using predictive analytics 2. Expanded air ambulance coverage for remote areas 3. Road infrastructure improvements to facilitate emergency access 4. Community-based first responder training programs
Moderate Fatality, Slow Response (Madina-type)	Extended response times with moderate outcomes	1. Optimization of dispatch and communication systems 2. Dynamic resource allocation based on temporal risk patterns 3. Continued infrastructure investment showing demonstrated correlation with response improvement

4.4.2. Holistic Road Safety Framework

Based on the key statistical findings of this study—specifically the weak link between response times and fatality rates, the primacy of pre-crash factors evidenced by the Aseer-Tabuk paradox, and the dual benefit of infrastructure investment—the following integrated, two-pronged strategy is proposed:

Primary Prevention Tier (Pre-Crash) [19]:

- Targeted infrastructure investment in high-risk regions.
- Enhanced traffic law enforcement with evidence-based deployment.
- Public education campaigns addressing region-specific risk factors.
- Vehicle safety standard monitoring and promotion.

Secondary Prevention Tier (Post-Crash) [20]:

- Strategic EMS resource allocation informed by geographic risk analytics.
- Infrastructure investments that simultaneously reduce accidents and improve response access.
- Advanced trauma care system development with regional specialization.
- Integration of technological solutions for reduced notification and dispatch intervals.

Cross-Cutting Enablers:

- Comprehensive data integration across traffic, health, and infrastructure domains.

- Regular regional risk profiling and resource reallocation.
- Legislative frameworks supporting evidence-based intervention prioritization.

5. Discussion

The findings of this study present a critical and counter-intuitive challenge to a long-standing assumption in road safety management: that faster ambulance response times are a primary, direct lever for reducing traffic fatalities. The analysis of Saudi Arabia's 2024 regional data reveals a landscape where this relationship is not only weak but often inverse, necessitating a fundamental re-evaluation of strategic priorities within a complex systems framework.

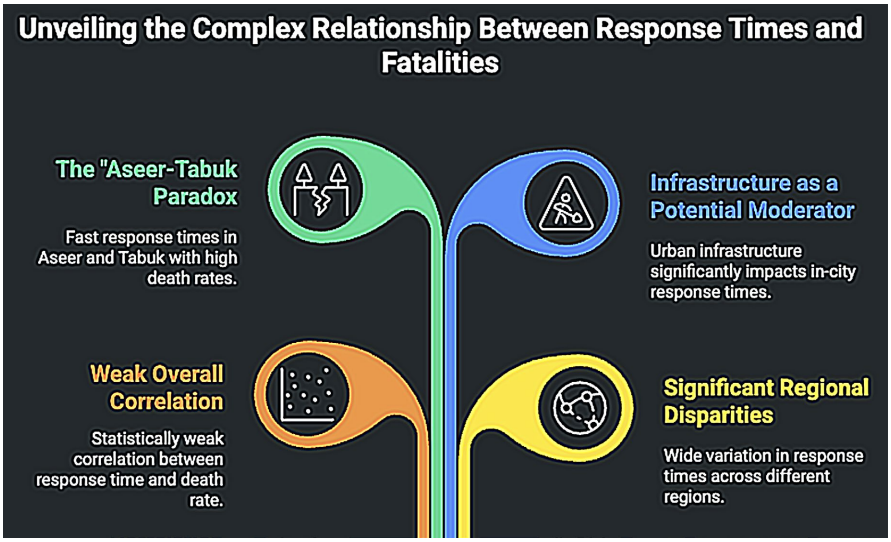

Figure 6. Summary of the key findings from the study: the paradoxical correlation, weak overall link, the moderating role of infrastructure, and significant regional disparities.

Figure 6 depicts the synthesis of the study's key findings, centering on the core "Aseer-Tabuk Paradox", which illustrates that regions like Aseer and Tabuk can simultaneously have relatively fast ambulance response times and yet experience high traffic fatality rates, challenging the simplistic assumption that faster EMS alone reduces deaths. This leads to the broader conclusion of a statistically weak overall correlation between response times and death rates, indicating that other critical factors are at play. The analysis identifies urban infrastructure, particularly the length of safety-standard road projects, as a significant moderator that improves *in-city* response efficiency but does not fully address rural challenges or underlying crash causes. Ultimately, the findings underscore the profound and significant regional disparities across the Kingdom, where a complex interplay of infrastructure, geography, and possibly behavioral factors dictates traffic safety outcomes more than any single EMS metric.

5.1. Deconstructing the Response Time Paradox

The weak negative correlation between out-of-city response times and death rates

($R \approx -0.09$) and the moderate negative correlation within cities ($R \approx -0.50$) are the study's most salient findings. This directly contradicts the intuitive "golden hour" logic when applied at a population-health level. The "Aseer-Tabuk Paradox" serves as the archetype: Aseer Region boasts the third-fastest out-of-city response (9.53 minutes) yet suffers the second-highest death rate (20.93), while Tabuk has a slow response (18.07 minutes) and the highest death rate (24.20). This divergence unequivocally demonstrates that factors occurring before the ambulance is called are the dominant determinants of whether a crash becomes a fatality.

The explanation lies in the nature of the accidents. Regions with fast responses but high death rates, like Aseer and Jazan, likely experience a high incidence of high-energy, high-severity crashes [21]. These could be due to mountainous terrain (Aseer), risky driver behavior, poor road design on specific corridors, or vehicle safety standards. Here, even exemplary EMS performance may be insufficient to overcome the lethality of the initial impact. Conversely, a region like Jazan, with the fastest response time (7.27 minutes) and the lowest death rate (7.40 per 100,000), may benefit from a combination of better road infrastructure (evidenced by high safety project completion rates), lower average speeds, or safer vehicle fleets, resulting in less severe crashes that are more survivable even with slightly delayed care.

5.2. The Primacy of Pre-Crash Factors and the "First Second"

This analysis strongly aligns with the World Health Organization's Safe Systems approach, which prioritizes the elimination of fatal and serious injury crashes [22]. Our data suggests that in the Saudi context, the "first second" of a crash—dictated by speed, seatbelt use, vehicle safety, and road engineering—is far more consequential than the "golden hour" that follows. The top causes of accidents cited in the annual report ("not leaving a safe distance", "sudden swerving") point to behavioral and infrastructural roots. Therefore, regions must be prioritized based on their *fatality rate*, not just their response time. Aggressive, targeted interventions in engineering (e.g., roadside barriers, improved geometry on high-fatality corridors), enforcement (targeting speeding and distraction), and education are non-negotiable for high-fatality regions like Tabuk, Aseer, and Al Baha, regardless of their EMS performance [23].

5.3. Response Time as a Critical Moderator, Not a Driver

To dismiss the importance of EMS would be an erroneous conclusion. Instead, the study repositions ambulance response time as a critical moderating variable. In a region with a *high baseline risk* of severe crashes (like Tabuk), slow response times exacerbate the fatality outcome, acting as a compounding risk factor [24]. Improving response here through air ambulances or dynamic deployment could yield significant marginal gains in lives saved [25]. Conversely, in a high-fatality region with already-fast responses (like Aseer), further incremental improvements in EMS speed may offer diminishing returns compared to the transforma-

tive potential of crash prevention. Thus, response time optimization is a vital component of a secondary prevention strategy, to be deployed strategically where it can have the greatest impact on mitigating outcomes when primary prevention fails.

5.4. The Dual Dividend of Infrastructure Investment

The strong positive correlation ($R \approx 0.74$) between the length of internal road safety projects and faster *in-city* response times is a powerful, actionable insight. It reveals that investments in traffic-calming measures, dedicated emergency lanes, and improved road design pay a dual dividend: they directly prevent crashes (primary prevention) and they enable emergency vehicles to navigate urban grids more efficiently (secondary prevention) [26]. This creates a virtuous cycle where safety infrastructure improves the effectiveness of the health response system. The stark underperformance in addressing internal road hazards in regions like Makkah (3%) and Madinah (3%) highlights a critical area for targeted investment that could simultaneously reduce crashes and improve EMS efficiency.

5.5. Navigating Geographic and Systemic Disparities

The extreme disparities in out-of-city response times (7.27 to 21.47 minutes) reflect Saudi Arabia's profound geographic and demographic challenges. The slow times in Riyadh and Madinah are likely a function of vast urban sprawl and complex hinterlands, not necessarily systemic failure [27]. This underscores that a one-size-fits-all national target (e.g., the 2024 target of 11 minutes) may be impractical. Strategy must be regionalized. For dense mega-cities, data-driven dynamic deployment of ambulances is key. For vast desert regions like Tabuk and the Northern Borders, the reported 33.65% increase in air ambulance flights is not just an achievement but a necessity, representing the most viable path to meaningful response time improvement.

5.6. Integration within a Whole-of-Government System

The study's findings validate the integrated structure of Saudi Arabia's Ministerial Committee for Traffic Safety. The complex interplay observed between health (response times), transport (road infrastructure), interior (enforcement), and education requires precisely such a multi-sectoral governance model. The data-driven approach, evidenced by the heat maps and the work of the Data Committee, is essential for moving beyond assumptions and targeting resources effectively. The challenge ahead is to ensure that the insights from such analyses—particularly the limited power of EMS alone to curb fatalities—fully translate into budget allocations and policy directives that robustly fund primary prevention.

6. Conclusions

This study conclusively demonstrates that the relationship between ambulance response times and traffic fatality rates in Saudi Arabia is not straightforward but

is intricately moderated by more powerful pre-crash factors. The initial hypothesis that slower responses directly cause higher death rates is an oversimplification that can lead to misallocated resources and missed opportunities to save lives.

The core conclusion is that road traffic fatalities in Saudi Arabia are predominantly determined in the moments before the crash. Factors such as road design, speed compliance, seatbelt usage, and vehicle safety set a regional "baseline risk" of death, which the emergency medical system can only mitigate, not overcome. The paradoxical cases of Aseer and Tabuk stand as stark evidence that excellent medical response cannot compensate for fundamentally unsafe road systems or user behavior.

Therefore, the strategic imperative must shift. A successful national road safety strategy requires a two-pronged, equally weighted approach:

1) Aggressive Primary Prevention: Unwavering focus on regions with high fatality rates, irrespective of their EMS performance. Resources must be directed toward evidence-based interventions in engineering (targeted infrastructure upgrades on high-risk corridors), enforcement (of speeding, seatbelts, and distraction), and education (sustained public awareness campaigns). The strong link between internal road projects and faster response times makes infrastructure investment a particularly high-leverage strategy.

2) Optimized Secondary Prevention: A strategic, context-sensitive enhancement of the emergency response system. This involves:

- **Regionalized Solutions:** Deploying air ambulances for vast, remote regions and advanced data analytics for dynamic ambulance placement in complex urban areas.
- **Infrastructure for Access:** Prioritizing road projects that include emergency access considerations.
- **Targeted Improvement:** Focusing EMS enhancement efforts on regions where slow response times are compounding a high baseline risk of severe crashes.

In summary, the path to achieving Saudi Vision 2030's traffic safety targets lies in recognizing that while a fast ambulance is crucial, it is the last line of defense. The most effective way to reduce fatalities is to build a road system and foster a driving culture where severe, life-threatening crashes are increasingly rare. This study provides the empirical foundation for rebalancing the nation's road safety portfolio, ensuring that the vital work of paramedics is supported by an even more vigorous commitment to preventing the tragedies to which they must respond.

Acknowledgments

The authors gratefully acknowledge the use of the following tools in the preparation of data visualizations for this study:

- **Datawrapper** for its intuitive and powerful chart creation capabilities.
- **Napkin AI** for assisting in the conceptualization and design of graphical summaries.

- **NoteGPT** for supporting the extraction and organization of data used in visual analysis.

These tools facilitated the effective communication of complex regional traffic safety data and enhanced the clarity of the findings presented in this paper.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Ameratunga, S., Hijar, M. and Norton, R. (2006) Road-traffic Injuries: Confronting Disparities to Address a Global-Health Problem. *The Lancet*, **367**, 1533-1540. https://doi.org/10.1016/s0140-6736(06)68654-6

[2] Alqahtany, A.M. (2025) Smart Cities as a Pathway to Sustainable Urbanism in the Arab World: A Case Analysis of Saudi Cities. *Sustainability*, **17**, Article 1525. https://doi.org/10.3390/su17041525

[3] Al-Shaqsi, S. (2010) Models of International Emergency Medical Service (EMS) Systems. *Oman Medical Journal*, **25**, 320-323. https://doi.org/10.5001/omj.2010.92

[4] Blackwell, T.H. and Kaufman, J.S. (2002) Response Time Effectiveness: Comparison of Response Time and Survival in an Urban Emergency Medical Services System. *Academic Emergency Medicine*, **9**, 288-295. https://doi.org/10.1197/aemj.9.4.288

[5] Omefe, S. (2025) Post-Crash Analysis and Injury Severity Prediction in Vehicle-Pedestrian Collisions Using Logistic Regression and AI-Based Predictive Analytics. *International Journal of Science and Research Archive*, **16**, 912-923. https://www.researchgate.net/profile/Samuel-Omefe/publication/393980977_Post-crash_analysis_and_injury_severity_prediction_in_vehicle-pedestrian_collisions_using_logistic_regression_and_AI-based_predictive_analytics/links/6882a83a0786937984544c7f/Post-crash-analysis-and-injury-severity-prediction-in-vehicle-pedestrian-collisions-using-logistic-regression-and-AI-based-predictive-analytics.pdf

[6] Newgard, C.D., Schmicker, R.H., Hedges, J.R., Trickett, J.P., Davis, D.P., Bulger, E.M., *et al.* (2010) Emergency Medical Services Intervals and Survival in Trauma: Assessment of the "Golden Hour" in a North American Prospective Cohort. *Annals of Emergency Medicine*, **55**, 235-246.e4. https://doi.org/10.1016/j.annemergmed.2009.07.024

[7] Regehr, C. and Bober, T. (2005) In the Line of Fire: Trauma in the Emergency Services. Oxford University Press. https://books.google.com/books?hl=en&lr=&id=fMJL5z46DtsC&oi=fnd&pg=PR7&dq=clinical+capability+of+first+responders+and+the+severity+of+the+initial+injury+are+often+more+critical+determinants+of+survival+than+mere+speed+of+arrival&ots=mshvNUZcoF&sig=bOtN8Sv1aJ23_J1l0C_kJqaYXnM

[8] Wang, C., Quddus, M.A. and Ison, S.G. (2013) The Effect of Traffic and Road Characteristics on Road Safety: A Review and Future Research Direction. *Safety Science*, **57**, 264-275. https://doi.org/10.1016/j.ssci.2013.02.012

[9] Shinar, D. (2017) Crash Countermeasures and Design of Safety. In: Shinar, D., Ed., Traffic Safety and Human Behavior, Emerald Publishing Limited, 1085-1175. https://www.emerald.com/insight/content/doi/10.1108/978-1-78635-221-720162019

[10] World Health Organization (2023) Pedestrian Safety: A Road Safety Manual for Decision-Makers and Practitioners. World Health Organization. https://books.google.com/books?hl=en&lr=&id=z6q9EAAAQBAJ&oi=fnd&pg=PR5&dq=WHO)+recommendations+for+road+safety+heavily+emphasize+legislation,+enforcement,+and+infrastructural+improvements+(like+traffic+calming+and+dedicated+pedestrian+facilities&ots=Rpi5pf2-UR&sig=teoFt04xIYr0Pq4kIPKhamfLsLw

[11] Djahel, S., Salehie, M., Tal, I. and Jamshidi, P. (2013) Adaptive Traffic Management for Secure and Efficient Emergency Services in Smart Cities. 2013 *IEEE International Conference on Pervasive Computing and Communications Workshops* (*PERCOM Workshops*), San Diego, 18-22 March 2013, 340-343. https://doi.org/10.1109/percomw.2013.6529511

[12] Alanazy, A.R.M., Wark, S., Fraser, J. and Nagle, A. (2019) Factors Impacting Patient Outcomes Associated with Use of Emergency Medical Services Operating in Urban versus Rural Areas: A Systematic Review. *International Journal of Environmental Research and Public Health*, **16**, Article 1728. https://doi.org/10.3390/ijerph16101728

[13] Almahdy, O. (2020) Making a Hot, Arid, Desert Arab City More Livable: Investigating the Role of Street Design in Enhancing Walkability in Riyadh, Saudi Arabia. Ph.D. Thesis, Illinois Institute of Technology. https://search.proquest.com/openview/4fa5f5e5cfa3e0b6a84de654ebbbd91e/1?pq-origsite=gscholar&cbl=44156&casa_token=FDlmPrxI-AhgAAAAA:Y4ymvwOMVj1vcAT-rPhucAljB-BHY-KwgEFw4QwI0R47kIpFB3aBw2sQ9J4mpoygRAf3LET-Rg

[14] Kingdom of Saudi Arabia (2024) Transport and Logistics Services. https://my.gov.sa/en/content/transport#section-6

[15] International Transport Forum (ITF) (2024) Road Safety Annual Report 2024. OECD Publishing. https://www.itf-oecd.org/sites/default/files/docs/irtad-road-safety-annual-report-2024.pdf

[16] Stanojević, P., Jovanović, D. and Lajunen, T. (2013) Influence of Traffic Enforcement on the Attitudes and Behavior of Drivers. *Accident Analysis & Prevention*, **52**, 29-38. https://doi.org/10.1016/j.aap.2012.12.019

[17] Mahdinia, I., Mohammadnazar, A. and Khattak, A.J. (2022) Understanding the Role of Faster Emergency Medical Service Response in the Survival Time of Pedestrians. *Accident Analysis & Prevention*, **177**, Article ID: 106829. https://doi.org/10.1016/j.aap.2022.106829

[18] Ehsani, J.P., Michael, J.P. and MacKenzie, E.J. (2023) The Future of Road Safety: Challenges and Opportunities. *The Milbank Quarterly*, **101**, 613-636. https://doi.org/10.1111/1468-0009.12644

[19] Kusano, K.D. and Gabler, H.C. (2010) Potential Occupant Injury Reduction in Precrash System Equipped Vehicles in the Striking Vehicle of Rear-End Crashes. *Annals of Advances in Automotive Medicine*, **54**, 203-214. https://pmc.ncbi.nlm.nih.gov/articles/PMC3242552/

[20] Yang, H., Wang, Z., Xie, K., Ozbay, K. and Imprialou, M. (2018) Methodological Evolution and Frontiers of Identifying, Modeling and Preventing Secondary Crashes on Highways. *Accident Analysis & Prevention*, **117**, 40-54. https://doi.org/10.1016/j.aap.2018.04.001

[21] Bahouth, G., Graygo, J., Digges, K., Schulman, C. and Baur, P. (2014) The Benefits and Tradeoffs for Varied High-Severity Injury Risk Thresholds for Advanced Auto-

matic Crash Notification Systems. *Traffic Injury Prevention*, **15**, S134-S140. https://doi.org/10.1080/15389588.2014.936011

[22] Khan, M.N. and Das, S. (2024) Advancing Traffic Safety through the Safe System Approach: A Systematic Review. *Accident Analysis & Prevention*, **199**, Article ID: 107518. https://doi.org/10.1016/j.aap.2024.107518

[23] Ajayi, P.O. (2022) Effectiveness of Saskatchewan Government Insurance 2014 Traffic Safety Initiatives on Reducing Casualties. Master's Thesis, The University of Regina (Canada). https://search.proquest.com/openview/65730a2ec1ca00009154c9d4725e78fe/1?pq-origsite=gscholar&cbl=18750&diss=y&casa_token=5Yp6yQGMAdQAAAAA:2CAORh3TktnAukXGayzo_1Qmq9ivpCWqWpy-JNsCcQJGUTmUnQPSakaSlqXQZu2lqWxzScWDq_A

[24] Hsiao, H., Chang, J. and Simeonov, P. (2018) Preventing Emergency Vehicle Crashes: Status and Challenges of Human Factors Issues. *Human Factors*, **60**, 1048-1072. https://journals.sagepub.com/doi/abs/10.1177/0018720818786132?casa_token=19L1S_Lja_UAAAAA:x6ovzM-eszlvju-8khrr17uA7Yov2fWUloiq-yAoA4p4i0oFt2KP09ZfiGwBPn9GTGXAr7sr9ZME

[25] Lejeune, M.A. and Margot, F. (2018) Aeromedical Battlefield Evacuation under Endogenous Uncertainty in Casualty Delivery Times. *Management Science*, **64**, 5481-5496. https://doi.org/10.1287/mnsc.2017.2894

[26] Litman, T. (1999) Traffic Calming: Benefits, Costs and Equity Impacts. Victoria Transport Policy Institute, 7 p. https://vtpi.org/calming.pdf

[27] Mubarak, F.A. (2004) Urban Growth Boundary Policy and Residential Suburbanization: Riyadh, Saudi Arabia. *Habitat International*, **28**, 567-591. https://doi.org/10.1016/j.habitatint.2003.10.010