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SPATIAL AND INFRASTRUCTURAL DETERMINANTS OF ROAD TRAFFIC MORTALITY IN KAZAKHSTAN: A VISION ZERO PERSPECTIVE TOWARD SDG INDICATOR 3.6.1

Purpose: This study aims to provide a comprehensive analysis of recent trends in road traffic accidents (RTAs) and road traffic mortality in Kazakhstan from demographic, spatial, and infrastructural perspectives. The research is grounded in the methodological frameworks of Sustainable Development Goal (SDG) indicator 3.6.1, the Safe System approach, and the Vision Zero concept.

Research methodology: A mixed-methods research design was utilized. The analysis draws on official national statistics for the period 2018–2022, reports from international organizations (WHO, OECD/ITF), and infrastructure safety assessment data from the International Road Assessment Programme (iRAP).

Findings: The findings indicate that despite a relative decline in the number of RTAs in Kazakhstan, the level of road traffic mortality has not decreased and has even increased in certain years. This pattern suggests that measures primarily aimed at reducing crash frequency have been insufficient in mitigating the severity of their consequences. A disproportionately high share of fatalities occurs within built-up areas, particularly among pedestrians and minors, highlighting fundamental shortcomings in the safety-oriented design of urban road infrastructure. iRAP assessments reveal that the majority of the road network is rated at 1-3 stars, underscoring the decisive role of infrastructural factors in road traffic mortality.

Originality: The study concludes that Kazakhstan's current road safety policies are inadequate to achieve the targets of SDG indicator 3.6.1 and emphasizes the need for systemic, prevention-oriented strategies based on Vision Zero principles. The results provide a scientific basis for improving road safety through the integration of spatial planning and infrastructure-focused policy interventions.

Keywords: Road traffic safety, road traffic accidents, mortality, Vision Zero, Safe System, iRAP, Sustainable Development Goals.

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Қазақстандағы жол-көлік өлім-жітімінің кеңістіктік және инфрақұрылымдық детерминанттары: Vision Zero және ТДМ 3.6.1 тұрғысынан талдау

Бұл зерттеу Қазақстандағы жол-көлік оқиғалары (ЖКО) мен олардан болатын өлім-жітімнің соңғы жылдардағы динамикасын демографиялық, кеңістіктік және инфрақұрылымдық тұрғыдан кешенді түрде талдауға бағытталған. Зерттеу Тұрақты даму мақсаты 3.6.1, Safe System және Vision Zero тұжырымдамаларының әдіснамалық негізінде жүзеге асырылды. Талдау 2018–2022 жылдар аралығындағы ресми ұлттық статистикаға, халықаралық ұйымдардың (WHO, OECD/ITF) есептеріне және iRAP инфрақұрылымдық қауіпсіздік бағалау деректеріне сүйенеді. Зерттеу нәтижелері Қазақстанда ЖКО санының салыстырмалы түрде төмендеуіне қарамастан, жол-көлік апаттарынан болатын өлім-жітім деңгейінің азаймай отырғанын және кейбір жылдары артқанын көрсетеді. Бұл құбылыс апаттардың жиілігін қысқартуға бағытталған шаралардың олардың салдарының ауырлығын төмендетуге жеткіліксіз екенін айқындайды. Өлім-жітімнің жоғары үлесі

елді мекендер ішінде, әсіресе жаяу жүргіншілер мен кәмелетке толмағандар арасында тіркелуі қалалық жол инфрақұрылымының қауіпсіздік тұрғысынан әлсіз жобаланғанын көрсетеді. iRAP бағалауы жол желісінің басым бөлігінің 1-3 жұлдызды қауіпсіздік деңгейіне ие екенін анықтап, инфрақұрылымдық факторлардың шешуші рөлін дәлелдейді. Зерттеу Қазақстанның жол қауіпсіздігі саласындағы қазіргі саясаты ТДМ 3.6.1 мақсаттарына жету үшін жеткіліксіз екенін және Vision Zero қағидаттарына негізделген жүйелік, алдын алуға бағытталған стратегияларды енгізу қажеттігін көрсетеді. Алынған нәтижелер жол қауіпсіздігін кеңістіктік жоспарлау мен инфрақұрылымдық саясатты қайта қарау арқылы жақсартуға ғылыми негіз ұсынады.

Түйін сөздер: жол-көлік қауіпсіздігі, жол-көлік оқиғалары, өлім-жітім, Vision Zero, Safe System, iRAP, Тұрақты даму мақсаттары.

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Пространственные и инфраструктурные детерминанты смертности в результате дорожно-транспортных происшествий в Казахстане: анализ с позиций Vision Zero и индикатора 3.6.1 ЦУР

Целью данного исследования является комплексный анализ динамики дорожно-транспортных происшествий (ДТП) и смертности в результате ДТП в Казахстане за последние годы с демографической, пространственной и инфраструктурной точек зрения. Методологической основой исследования послужили индикатор 3.6.1 Цели устойчивого развития, концепция Safe System и философия Vision Zero. Анализ основан на официальной национальной статистике за 2018–2022 гг., отчетах международных организаций (ВОЗ, OECD/ITF), а также данных оценки безопасности дорожной инфраструктуры программы International Road Assessment Programme (iRAP). Результаты исследования показывают, что, несмотря на относительное сокращение числа ДТП в Казахстане, уровень смертности в результате дорожно-транспортных происшествий не снижается и в отдельные годы демонстрирует рост. Это свидетельствует о том, что меры, ориентированные преимущественно на сокращение частоты аварий, оказались недостаточными для снижения тяжести их последствий. Высокая доля погибших в пределах населенных пунктов, особенно среди пешеходов и несовершеннолетних, указывает на существенные недостатки в безопасности городского улично-дорожного пространства. Оценки iRAP показывают, что большая часть дорожной сети относится к 1-3 звездочному уровню безопасности, что подтверждает ключевую роль инфраструктурных факторов в формировании смертности на дорогах. В заключение подчеркивается, что текущая политика в сфере дорожной безопасности в Казахстане является недостаточной для достижения целевых показателей индикатора 3.6.1 ЦУР и требует внедрения системных, профилактически ориентированных стратегий, основанных на принципах Vision Zero. Полученные результаты формируют научную основу для повышения безопасности дорожного движения за счет пересмотра пространственного планирования и инфраструктурной политики.

Ключевые слова: безопасность дорожного движения, дорожно-транспортные происшествия, смертность, Vision Zero, Safe System, iRAP, Цели устойчивого развития.

Introduction

Road traffic accidents (RTAs) are one of the most pressing public health and sustainable development issues globally. According to the World Health Organization, road traffic accidents kill an estimated 1.2–1.3 million people and injure tens of millions more each year (WHO, 2018). Research over the past decade has clearly shown that this problem is not limited to transport safety alone, but is shaped by the interaction of spatial planning, infrastructure quality, management systems, and human behavior (Yang et al., 2020; Zhang, 2023).

Road Safety and the Sustainable Development Goals: The Sustainable Development Goals (SDGs) adopted by the United Nations in 2015, target 3.6.1, aim to reduce road traffic fatalities by at least half by 2030. However, recent reviews show that many countries are not on track to achieve this goal, particularly in middle- and high-income countries with weak infrastructure (OECD&ITF, 2018; WHO, 2023).

The Vision Zero philosophy is widely discussed in the scientific literature as one of the most effective strategic approaches to road safety. According to studies by He et al. (2022) and Mofolasayo (2024), countries that have implemented Vision Zero have seen a significant reduction in road fatalities. This concept recognizes the potential for road user error and considers the design of road systems to be such that those errors do not lead to fatalities.

The relationship between human factors and infrastructure: The current scientific consensus on the causes of road accidents indicates that the human factor is involved in 90–95% of accidents. However, research over the past decade has shown that explaining the human factor in terms of individual responsibility alone is not enough Khan and Das (2024) and Elvik (2020) show that dangerous driver behavior is largely predetermined by the spatial configuration and engineering design of the road.

In this context, studies based on the iRAP (International Road Assessment Program) methodology are of particular importance. (iRAP, 2019) and Welle et al. (2018) have shown that the risk of death on 4–5-star safety roads is several times lower than on 1–2-star roads. This indicates that infrastructure safety is a key factor in reducing the severity of road accidents.

Urbanization and Socio-Spatial Inequality: Recent urban studies have shown that a significant proportion of road traffic fatalities occur within settlements, especially among pedestrians and children (Adanu et al., 2023; Islam et al., 2022). This phenomenon suggests that transport-oriented urban planning models are at odds with the principles of social justice.

The presence of pedestrians and children as a vulnerable group is considered in the scientific literature as an important indicator for assessing the quality of road infrastructure. Such studies have identified "forgiving road design", speed limits in school zones and safe crossings as the most effective tools for reducing fatalities (Elvik et al., 2019; Lie et al., 2024).

Research gap in the context of Kazakhstan: Road safety research for Central Asian countries is limited and is often limited to descriptive statistics. Although the high level of road traffic fatalities in Kazakhstan is noted in published works, its spatial and infrastructural causes are rarely analyzed in a comprehensive manner (WB, 2020). This situation does not allow for a full understanding of the main obstacles to achieving the SDG 3.6.1 target. Therefore, the main goal of this research is to analyze the dynamics of road accidents and fatalities in Kazakhstan in recent years from a demographic, spatial and infrastructure perspective, and to interpret the results obtained in the context of the SDG objective 3.6.1 and the principles of Vision Zero.

Literature review

Global Paradigms for Road Safety – Safe System and Vision Zero: The scientific research over the past decade has identified the Safe System and Vision Zero paradigms as key concepts for ensuring road safety. These approaches consider the structural weaknesses of the road system, rather than individual error, as the primary cause of road accidents. The scientific consensus is that human error will always occur, and therefore the transport system should be designed to prevent these errors from leading to death or serious injury (Elvik et al., 2019; Kharoufah et al., 2018).

Numerous country and comparative studies have shown that countries that have comprehensively implemented Vision Zero principles have reduced road traffic fatalities by 40–60% (Ecola et al., 2018; OECD&ITF, 2018). This reduction is achieved not only through legal controls, but also through infrastructure redesign, speed management, and data-driven policies. In this context, the World Health Organization considers Vision Zero and Safe System as key tools for achieving MDG target 3.6.1 (WHO, 2018, 2023).

The crucial role of infrastructure safety and road design: One of the main factors determining the severity of road accidents is the level of road safety infrastructure. Studies over the past decade have shown that most accidents occur in favorable weather and road conditions, but their fatality is directly related to the geometry and engineering design of the road (Elvik, 2020; Welle et al., 2018). Studies based on the iRAP methodology have shown that the risk of death on 4–5-star roads is several times lower than on 1–2 star roads (iRAP, 2019). These scientific results indicate that preventive engineering design is more important than post-accident measures in improving road safety. Especially in urban areas, "forgiving road design" has been shown to significantly reduce the consequences of accidents (Wegman et al., 2015).

Human factors, speed and risky behaviour: The international scientific literature confirms that human factors are involved in 90–95% of road accidents, but this factor is not considered solely in the context of individual responsibility (Elvik, 2020;

WHO, 2018). Many studies show that risky driver behaviour (speeding, non-compliance with traffic rules, alcohol use) is largely dependent on the nature of the road space.

Speed management is recognized as one of the most effective tools for reducing road fatalities. Systematic reviews show that limiting urban speed limits to 30–50 km/h significantly reduces pedestrian fatalities (Lubbe et al., 2022; OECD&ITF, 2018). In addition, many national studies have proven that integrated policies (punishment, inspection, technological control) are effective in reducing accidents involving drunk drivers (Elvik et al., 2019; Lym & Chen, 2020).

Urbanization, spatial inequality and vulnerable groups: Recent literature shows that a significant proportion of road traffic fatalities occur within settlements, especially among pedestrians and children (WHO, 2018, 2023). This situation demonstrates that transport-oriented urban planning is not in line with the principles of social justice.

Inadequate infrastructure for children and pedestrians (safe crossings, school zones, traffic calming elements) aggravates the consequences of accidents (Elvik, 2020; Katoch et al., 2025). In scientific works, road safety is considered not only as a technical issue, but also as a component of spatial planning and social policy.

Research gap in the context of Kazakhstan and similar countries: Research for middle-income and large-scale countries shows that the pace of road traffic fatality reduction is slow and that the main reasons are poor infrastructure safety, weak data systems and reactive policies (OECD&ITF, 2018; WB, 2020). While published works on Kazakhstan highlight the high level of road traffic fatalities, few studies have comprehensively analyzed their spatial and systemic causes.

Given this research gap, assessing road traffic safety in the context of Kazakhstan within the framework of Vision Zero, iRAP and SDG 3.6.1 is relevant. This study aims to reveal the structural problems in the field of road safety in Kazakhstan and to justify effective policies, based on international scientific evidence.

Methodology

Research design and methodological approach: This study aims to comprehensively analyze the spatial, demographic, and infrastructural characteristics of road traffic accidents (RTAs) and their associated deaths in Kazakhstan. The study is based on a descriptive-analytical design and uses a mixed methodological approach that combines elements of quantitative statistical analysis and qualitative interpretation.

The formation of the research work was directly influenced by the participation of the 1st author in a research assignment implemented within the framework of the "Sustainable Development Goals" discipline taught at the University of California, Davis (UC Davis). Within the framework of this project, the researchers were tasked with selecting a country with which they had extensive knowledge and analyzing the level of implementation of the Sustainable Development Goals using the example of that country.

In this context, Goal 3 of the Sustainable Development Goals – ensuring healthy lifestyles and promoting well-being for people of all ages – was taken as the main guideline in determining the topic of the study. When choosing the topic, the author of the study was concerned that the level of deaths and injuries due to road accidents in Kazakhstan remains high and is not steadily decreasing. This situation necessitated an in-depth analysis of Kazakhstan within the framework of SDG target indicators 3.6.1, which focuses on reducing the global rate of death caused by road traffic accidents.

The Safe System and Vision Zero concepts, as well as indicators of Sustainable Development Goal 3.6.1, were adopted as the methodological basis. The Vision Zero Network is a collaborative campaign to help communities eliminate traffic deaths and serious injuries while promoting safe, equitable mobility. The study allows assessing road safety not only in terms of the number of accidents, but also in terms of the severity of their consequences, spatial distribution and social impact.

Sources and Databases: The data used in the study were collected from several official and international sources, including:

- Official statistical data on road accidents, fatalities and injuries (2018–2022) published by the authorized state bodies of the Republic of Kazakhstan;
- Reports and databases of international organizations on road safety;
- Data obtained within the framework of international programs for assessing the safety level of road infrastructure;
- International scientific literature and secondary sources for comparative analysis.

All data were checked for time consistency, comparability and compliance with international standards.

Analysis methods: The following analysis methods were used in the study:

• Descriptive statistical analysis – to determine the time dynamics of the number of road accidents, fatalities and injuries;

• Comparative analysis – to compare Kazakhstan's indicators with international practice and SDG 3.6.1 target indicators;

• Structural-demographic analysis – to assess the structure of road accidents by gender, age and road user categories;

• Spatial-interpretive analysis – to explain the distribution of road accidents within and between settlements, as well as their relationship with the level of infrastructure safety;

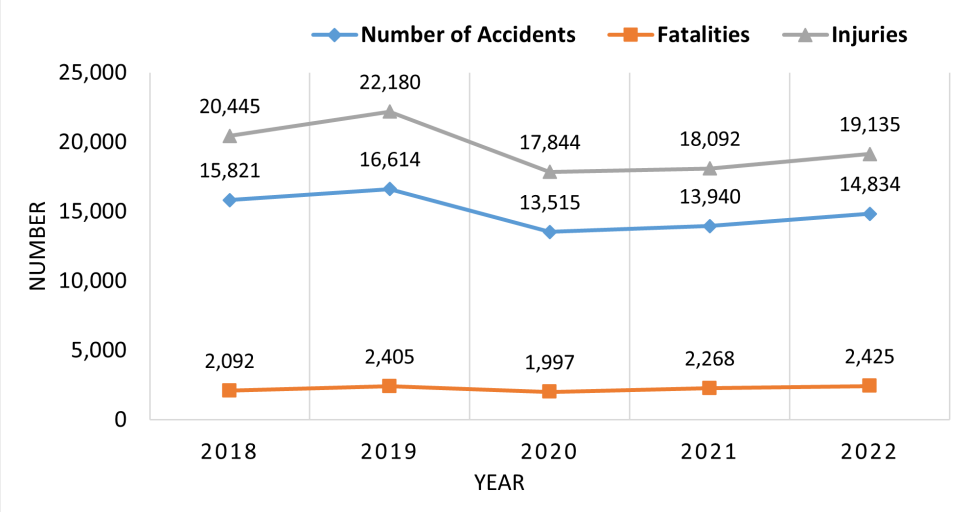
• Infrastructure safety assessment – the level of road network safety was analyzed based on star ratings.

The study results were interpreted in terms of the principles of Vision Zero and the Safe System approach and served as the basis for drawing policy and practical conclusions aimed at improving road safety in Kazakhstan.

Results and discussion

Dynamics and consequences of road accidents in Kazakhstan: The dynamics of road accidents (RAs) in Kazakhstan over the period 2018–2022 shows a relatively decreasing trend in terms of numbers, but their severity has increased. As shown in Figure 1, the number of RAs decreased in 2018–2019, stabilized in 2020–2021, and decreased again in 2022. This trend is explained by the strengthening of traffic regulation measures and restrictions on mobility during the COVID-19 pandemic.

Figure 1
General dynamics of road accidents in Kazakhstan (2018–2022)



Note: compiled by the author based on Bureau of National Statistics of the Republic of Kazakhstan

However, the data presented in Table 1 show that despite an average decrease in the number of road accidents by –6.2%, the number of fatalities increased by +15.9%. This paradoxical situation means that although road accidents are rare, the likelihood of them causing fatalities has increased.

That is, the problem is shifting not only to the number of accidents, but also to the severity of incidents. This trend may be due to low safety standards of road infrastructure, high speed, and insufficient use of safety equipment (seat belts, child seats, motorcycle protection).

Table 1
Average values and rates of change of road accident indicators in Kazakhstan

Indicator	Average value (2018–2022)	Change, %
Number of road accidents	14 945	−6.2
Number of fatalities	2 237	+15.9
Number of injuries	19 539	−6.4

Note: compiled by the author based on data from Bureau of National Statistics of the Republic of Kazakhstan

Mortality structure and demographic characteristics: The level of road traffic fatalities in Kazakhstan is high by international standards. According to Table 2, the fatality rate per 100,000 people is between 11.5 and 12.2, and approximately 2,000 people die in road accidents each year. These figures clearly demonstrate the socio-economic importance of the road safety issue.

Table 2
Key indicators of road traffic fatalities in Kazakhstan (2021)

Indicator	Value (People)
Mortality (per 100,000 people)	11.5–12.2
Annual deaths	≈2 000
Deaths per 100,000 vehicles	53
every 56 minutes	1 person dies

Note: compiled by the author based on data from World Health Organization (2023) and Bureau of National Statistics of the Republic of Kazakhstan

The demographic structure of fatalities is characterized by a clear gender imbalance. As shown in Table 3, 73% of fatalities are men, while the share of women is 27%. This difference is explained by the predominance of risky behavior, high speed driving, and the share of professional drivers among men. In addition, the high share of pedestrian fatalities (27%) indicates the inadequacy of urban pedestrian infrastructure (crosswalks, lighting, islands).

Table 3
Demographic structure of road traffic deaths

Indicator	Share (%)
Women	27
Men	73
Pedestrians	27
Other road users	73

Note: compiled by the author based on data from Bureau of National Statistics of the Republic of Kazakhstan and World Health Organization (2018)

Results of Regression Analysis: The high proportion of juvenile deaths (approximately 10.6%) is of particular concern and demonstrates the weakness of spatial planning and speed limit measures for child safety in Kazakhstan.

Spatial and infrastructure factors: The geographical distribution of road accidents shows clear inter-regional differences. Almaty city has the highest rate, accounting for about 25 % of all road accidents, which is associated with high traffic density and urbanization. Almaty region has the highest mortality rate, which is explained by the lack of long-distance roads, high-speed mode and low availability of emergency medical care. Analysis of the functional significance of roads shows that about 75% of road accidents occur within settlements (KINA, 2023). This data indicates a poor design of the city's street-road network from a safety perspective and ineffective traffic management.

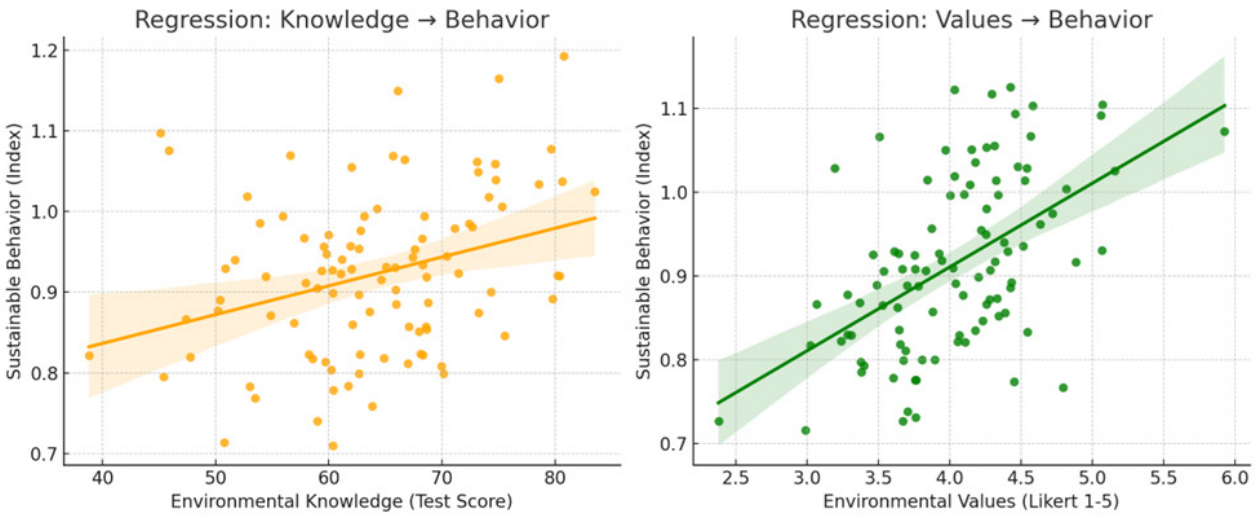
Figure 2 shows a clear disparity in the level of safety for different groups of road users. The highest share of roads rated 3 stars and above according to the iRAP methodology is observed for cyclists (35%) and light vehicle passengers (33%). This indicates that the infrastructure elements (road width, traffic mode, engineering solutions) for these groups are relatively better developed.

The share of safe roads for pedestrians (22%) and especially motorcyclists (14%) is significantly lower. This indicates a lack of pedestrian crossings, weak speed limit measures, and shortcomings in the infrastructure aimed at protecting vulnerable road users.

The low level of infrastructure safety is clearly demonstrated by the iRAP assessment presented in Figure 2: the majority of Kazakhstan's road network has a safety level of 1–3 stars, and the proportion of safe sections with 4–5 stars is very small. This indicates that road design is not aimed at preventing accidents, but only at limiting their consequences.

Time and Environmental Factors: The time structure of road accidents (RAs) is closely related to the intensity of road traffic and social rhythms in society. Official statistical data for Kazakhstan show that the highest proportion of road accidents during weekdays falls on Mondays and Saturdays. This phenomenon is explained, on the one hand, by a sharp increase in traffic flow associated with the beginning of the working week, and on the other hand, by an increase in personal and recreational trips on weekends.

Figure 2
Road Infrastructure Safety Assessment (iRAP) in Kazakhstan



Note: compiled by the authors based on the statistics from International Road Assessment Program (iRAP) and Vaccines for Roads Database

Analysis by time of day reveals that the majority of road accidents occur during the daytime. According to official data, about 68% of all RAs are registered during the day, while twilight and nighttime account for 19% and 12%, respectively (KR, 2022). These indicators indicate that the busiest period of road traffic corresponds to the daytime, and as a result, the risk of accidents increases. The study data shows that the share of daytime accidents is determined at 61.3%, which is consistent with national statistics (ATO, 2025).

The analysis of road conditions also confirms that road accidents are more closely related to the human factor than to natural and climatic factors. The majority of road accidents registered in Kazakhstan, namely 77.1%, occurred on dry road surfaces (ATO, 2025). According to official data, 7,864 accidents were recorded on dry roads, 674 on wet roads, 309 on snowy roads, and 115 on icy roads (KR, 2022).

These data prove that human factors, such as driver speeding, traffic violations, and distraction, play a decisive role in increasing road safety, rather than adverse weather conditions or road surface conditions. Thus, the structure of road accidents by time and road conditions clearly demonstrates the importance of behavioral and management measures in improving road safety.

I*nterpretation of road safety trends in Kazakhstan in the context of SDG 3.6.1:* The results of the study showed that the number of road traffic accidents (RTAs) in Kazakhstan has decreased relatively in recent years, but the mortality rate has continued to increase. In the international literature, this situation is described as the "severity paradox", that is, although the frequency of accidents has decreased, the severity of their consequences has increased (Elvik et al., 2019). This phenomenon indicates that road safety policies remain predominantly reactive and are focused on combating the consequences of accidents rather than preventing their root causes.

According to reports published by the World Health Organization and OECD/ITF, reducing the number of road traffic accidents is not enough to achieve Sustainable Development Goal 3.6.1; the main priority should be to prevent deaths and serious injuries, i.e. to improve the safety of the road system .(OECD&ITF, 2018; WHO, 2018). Current indicators in Kazakhstan indicate that these requirements are not being fully met and that the country is at risk of falling short of its 2030 commitments.

Table 4
Kazakhstan's compliance with the 2030 goals and international comparison

Indicator	Share (%)
Women	27
Men	73
Pedestrians	27
Other road users	73

Note: compiled by the author based on (OECD&ITF, 2018; WB, 2020; WHO, 2018, 2023)

In order to better understand the results in the context of SDG 3.6.1, Kazakhstan's road safety performance was assessed in comparison with international practice and the targets set for 2030 (Table 4). As shown in Table 4, the actual annual mortality reduction rate in Kazakhstan (approximately 4.3%) is significantly lower than the target rate (7.4%). This difference indicates the inadequacy of existing measures and the need for fundamental changes in policy.

In addition, the international comparison presented in Table 4 reveals that Kazakhstan's position in the field of road safety is intermediate: on the one hand, the country lags significantly behind the countries that have implemented the advanced Vision Zero strategy (Sweden, Norway), and on the other hand, it is slightly higher than countries in a state of infrastructural and institutional crisis. For example, in Sweden and Norway, a steady reduction in fatalities has been ensured by safe road design, strict speed management, legal control, and the systematic formation of a traffic culture.

In the case of Kazakhstan, on the other hand, as shown in Table 4, the road safety strategy remains fragmented: the level of infrastructure safety is low, the data and monitoring system is incomplete, and prevention measures are not systematically integrated. As a result, the reduction in the number of road accidents has not been accompanied by a decrease in fatalities, but rather the risk of their severe consequences remains. This situation highlights the need to shift the policy from a reactive approach to a proactive, systematic and evidence-based approach if Kazakhstan is to achieve the SDG 3.6.1 objective.

A comprehensive discussion of infrastructure, human factors and social risks from the perspective of Vision Zero and Safe System: The results of the study clearly demonstrate the structural weakness of the road safety system in Kazakhstan compared to the main principles of the Vision Zero and Safe System concepts. The Vision Zero philosophy assumes that human error is a natural phenomenon and that the road system should be adapted so that it does not lead to death or serious injury (Tingvall & Haworth, 1999). However, the empirical results obtained, in particular the low level of infrastructure safety and the widespread use of high-speed modes, indicate that these principles have not been systematically and comprehensively implemented in Kazakhstan.

The study found that the majority of road accidents occur in populated areas, which is a relatively high indicator compared to international practice. The high level of fatalities in urban areas indicates that the road infrastructure is oriented not to safety, but to vehicle capacity. In the scientific literature, such a planning approach is described as a "mobility-oriented planning trap", that is, speeding up traffic becomes a priority, while safety is relegated to second place (Wegman et al., 2022).

International studies based on the iRAP methodology prove that there is a direct relationship between the star safety level of roads and the risk of death: on roads with a star rating of 1–2, the risk of death is several times higher than on roads with a star rating of 4–5 (iRAP, 2019; Welle et al., 2018). The fact that a significant part of the road network in Kazakhstan has a low and medium safety level explains the high proportion of deaths identified in the study from a spatial perspective.

In addition, the results of the study showed that the majority of road accidents occur in favorable road and weather conditions. This is consistent with the widely proven conclusion in the international literature: the main cause of road accidents is not external factors, but the speed regime and risky behavior of drivers (Elvik, 2020). WHO and OECD/ITF studies show that urban speed management measures (30–50 km/h) significantly reduce deaths among pedestrians and children (OECD/ITF, 2020; WHO, 2017). The fact that speed management in Kazakhstan is mainly implemented through enforcement and penalties, and that there are limited mechanisms for reducing speed through road design, is fully consistent with the findings of the study.

Demographically, the identification of men aged 30–39 as the highest risk group is consistent with international studies. The high proportion of deaths in this group increases the economic and social costs associated with the loss of the working-age population (Rosen et al., 2022). In addition, the significant proportion of deaths among children and pedestrians highlights the social justice dimension of road

safety. The scientific literature has repeatedly demonstrated that the consequences of road accidents are more severe if spatial safety measures aimed at children (school zones, low speed zones, safe crossings) are not implemented (Elvik, 2020; Tingvall & Haworth, 1999).

Policy and strategic implications and coherence with international experience: The analysis conducted highlights the need for institutional and strategic reorientation in the field of road safety in Kazakhstan. OECD/ITF and World Bank studies highlight the fragmentation of governance, weak data systems, and insufficient level of infrastructure safety as the main obstacles to reducing road traffic fatalities in middle-income countries (OECD&ITF, 2018; WB, 2020). These factors are also clearly visible in the case of Kazakhstan.

International experience shows that countries that have comprehensively implemented the principles of Vision Zero (Sweden, Norway, the Netherlands) have reduced road traffic fatalities by 40–60% (Elvik et al., 2019; Wegman et al., 2015). The dynamics of road traffic fatalities in Kazakhstan prove that to achieve such results, systemic and fundamental changes are needed, rather than individual measures.

In this context, the national adaptation of Vision Zero principles, infrastructure modernization based on the iRAP methodology, and the introduction of a data-driven management system are the most likely and scientifically sound directions for reducing road fatalities for Kazakhstan. Such an approach allows us to consider road safety not only as the responsibility of individual drivers, but as an integral component of state policy and spatial planning.

Conclusion

This study, through a comprehensive analysis of the road safety situation in Kazakhstan, made it possible to draw a number of important scientific and applied conclusions. The results of the study showed that despite the relative decrease in the number of road accidents in recent years, the mortality rate has remained or increased. This situation indicates that the measures taken in the field of road safety are aimed not at preventing the consequences of accidents, but rather at reducing their frequency.

The data obtained indicate the structural nature of the road safety problem in Kazakhstan: the high level of mortality is closely related to low infrastructure safety, high speed, traffic-oriented planning of urban space, and insufficient attention to vulnerable road users (pedestrians, children). The iRAP assessment shows that the majority of the road network has a safety level of 1–3 stars, explaining the risk of accidents with serious consequences in a spatial context.

The study found that Kazakhstan is at risk of deviation from its commitments under Sustainable Development Goal 3.6.1. The actual rate of fatality reduction is significantly lower than the target indicators, which indicates the need for a fundamental review of road safety policies. Comparison with international experience proves that the achieved results will be limited if the principles of Vision Zero and Safe System are not systematically implemented.

From a scientific point of view, this study demonstrates the importance of interpreting road safety in the context of Kazakhstan through spatial planning, infrastructure design and social justice dimensions. From a practical point of view, the study results can serve as a basis for reorienting the national road safety strategy, accelerating infrastructure modernization based on iRAP, and introducing a data-driven management system.

In conclusion, reducing road traffic fatalities in Kazakhstan should not be limited to legal controls or behavioral interventions alone. To achieve effective results, a systematic, prevention-oriented and evidence-based road safety policy in accordance with the principles of Vision Zero is needed.

The study has a number of limitations, including the following. First, the analysis is based mainly on aggregated national and regional data, which limits analysis at the micro-level (individual road sections, specific accident scenarios). Second, some indicators of road traffic accident data (injury severity, behavioral factors) are not fully standardized. However, the methodological approaches used minimize these limitations and allow for systematic conclusions.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

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