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A SYSTEMS APPROACH TO ENSURING ROAD TRAFFIC SAFETY IN MOTOR TRANSPORT

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Abstract: Road traffic safety is a complex socio-technical problem resulting from the interaction of human, vehicle, infrastructure, environmental, technological, and institutional factors. This article develops a systems-based framework for improving road traffic safety in motor transport by integrating systems thinking, risk management, and the Safe System approach. The study applies conceptual systems analysis and risk modelling to identify the principal components of the road transport safety system and their interactions. A systemic risk model is proposed that considers probability, exposure, consequence severity, and interactions among risk factors. The framework incorporates road users, vehicles, infrastructure, speed management, governance, and post-crash response. The study demonstrates that effective road safety management requires a transition from predominantly reactive crash prevention toward proactive and continuous risk management. Data integration, shared institutional responsibility, measurable performance indicators, and continuous monitoring are identified as key conditions for effective implementation. The proposed framework can support evidence-based road safety strategies at national, regional, and municipal levels.

Keywords: road traffic safety; systems approach; Safe System; road transport; systemic risk; road infrastructure; vehicle safety; speed management; road safety governance.

Introduction. Road transport is essential for economic and social development, but increasing motorisation and mobility demand also create significant safety risks. According to the World Health Organization, approximately 1.19 million people die annually in road traffic crashes worldwide. More than half of these fatalities involve vulnerable road users such as pedestrians, cyclists, and motorcyclists.

Road crashes are rarely the result of a single factor. Human behaviour, vehicle characteristics, road infrastructure, speed, environmental conditions, traffic management, and institutional arrangements interact to determine both crash probability and severity.

This complexity requires a transition from isolated interventions toward a systems approach. The Safe System concept recognises that humans make mistakes and that the transport system should be designed so that such mistakes do not result in death or serious injury. The United Nations has adopted the objective of reducing global road traffic deaths and injuries by at least 50% by 2030.

The objective of this study is to develop a conceptual framework for applying a systems approach to road traffic safety in motor transport.

Theoretical Background.

Traditional road safety approaches frequently emphasise individual driver behaviour. However, contemporary systems research considers road transport a complex socio-technical system in which safety emerges from interactions between its components.

The overall safety level can therefore be represented as:

$$S = f(H, V, I, S_p, E, G, P),$$

where:

H – human factors;

V – vehicle factors;

I – infrastructure;

S_p – speed;

E – environmental conditions;

G – governance;

P – post-crash response.

The Safe System approach expands responsibility beyond individual road users to include road authorities, vehicle manufacturers, infrastructure designers, law-enforcement agencies, emergency services, and policymakers. Research demonstrates the value of systems thinking for identifying latent risks and interactions that conventional crash-based approaches may overlook.

Methodology.

The study uses conceptual systems analysis, risk assessment, and systems modelling.

A basic risk model is expressed as:

$$R_i = P_i \times E_i \times C_i ,$$

where:

R_i – risk associated with hazard ii;

P_i – probability of occurrence;

E_i – exposure;

C_i – consequence severity.

Because risks interact, systemic risk can be represented as:

$$R_{sys} = \sum_{i=1}^{n} R_i + \sum_{i \neq j} \lambda_{ij} R_i R_j ,$$

where

i and j – two different risk factors;

R_i and R_j – risks associated with these factors;

λ_{ij} – interaction coefficient between the two risk factors.

The proposed management cycle is: Data → Risk Identification → Risk Assessment → Intervention → Monitoring → Feedback.

This structure enables continuous adaptation of safety measures according to observed results.

Systems Framework for Road Traffic Safety.

The proposed framework integrates six principal dimensions:

1. Human factors – speed choice, distraction, fatigue, impairment, and compliance with traffic regulations.

2. Vehicle safety – active and passive safety technologies.

3. Infrastructure – road geometry, intersections, lighting, pedestrian facilities, pavement condition, and roadside protection.

4. Speed management – appropriate speed limits, traffic calming, enforcement, and intelligent speed technologies.

5. Governance – coordination between transport authorities, municipalities, police, emergency services, and other stakeholders.

6. Post-crash response – crash detection, emergency dispatch, rescue, medical treatment, and rehabilitation.

The model emphasizes that road safety is a continuous process rather than a single intervention.

Human and behavioral factors. Important behavioral risks include excessive speed, distracted driving, fatigue, impaired driving, and non-compliance with safety requirements. However, these factors should not be considered independently of the surrounding transport environment.

Vehicle safety. Active safety technologies, including electronic stability control and advanced emergency braking, can reduce crash probability. Passive safety systems such as seat belts, airbags, and energy-absorbing structures reduce injury severity.

Infrastructure. Road design should account for human limitations and foreseeable errors. Important measures include safe intersections, pedestrian separation, appropriate lighting, traffic calming, median protection, and roadside safety.

Governance and data. Effective road safety requires shared responsibility and integrated data. Crash records should be combined with traffic flow, speed, infrastructure, vehicle inspection, weather, emergency response, and GIS data.

This allows authorities to identify risks before they necessarily result in severe crashes.

Road Safety Performance Indicators.

A systems approach should use both outcome and process indicators (1-Tabl).

Dimension	Indicator
Fatality	Road deaths per year
Injury	Serious injuries
Exposure	Fatalities per vehicle-km
Speed	Speed compliance rate
Seat belts	Seat-belt use
Infrastructure	Safety compliance
Vehicles	Technical compliance
Emergency response	Response time
Governance	Action-plan implementation
Data	Data completeness

A composite Safety Performance Index may be expressed as:

$$SPI = \sum_{i=1}^{n} w_i X_i ,$$

where

SPI – Safety Performance Index, representing the overall road traffic safety performance level;

w_i – the weighting coefficient assigned to the i - th indicator;

X_i – the normalized value of the i - th safety performance indicator;

n – the total number of indicators included in the assessment.

The weights should be empirically determined before practical application.

Discussion. The systems approach represents a shift from reactive crash analysis toward proactive risk management. Instead of waiting for repeated crashes at a location, authorities can identify combinations of risk factors such as excessive speed, poor visibility, high pedestrian exposure, and inadequate infrastructure.

International research supports the integration of safe roads, safe speeds, safe vehicles, safe road users, and post-crash care within a unified Safe System framework.

A major requirement is institutional coordination. Road safety measures implemented independently by different organizations may have limited effectiveness. A common strategy, integrated databases, measurable indicators, and regular evaluation are therefore necessary.

Digital technologies can strengthen this approach through real-time traffic monitoring, automated speed detection, intelligent traffic signals, GIS-based risk mapping, and vehicle telematics.

Conclusions. Road traffic safety should be understood as a property of the entire motor transport system rather than as the responsibility of individual road users alone.

The proposed systems framework integrates human behavior, vehicles, infrastructure, speed, governance, environmental conditions, and post-crash response. Its principal methodological advantage is the integration of risk identification, assessment, intervention, monitoring, and feedback into a continuous management cycle.

The study demonstrates that effective road safety policy should:

– adopt Safe System principles;
– identify systemic rather than isolated risks;
– integrate transport and safety data;
– establish shared institutional responsibility;
– use measurable safety performance indicators;
– priorities proactive risk reduction;
– continuously evaluate intervention effectiveness.

Further research should validate the proposed framework using national crash databases, GIS analysis, statistical modelling, and longitudinal data. Such empirical validation would allow the development of quantitative road safety models adapted to specific national and regional conditions.

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