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New Technologies for Sustainable Mobility: A Simulator-Based Approach to Risk Assessment and Transport Safety

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Abstract:

Background

Transport systems are a crucial component of modern society, linking spaces, facilitating economic growth and enabling cultural exchange. However, the environmental footprint of the transport sector remains a pressing challenge, with approximately 25% of global energy consumption and carbon dioxide emissions originating from transportation. Current transportation practices are not sustainable, with reports indicating that greenhouse gas emissions from the sector are rising more rapidly than in any other energy-consuming domain, particularly in urban areas.

Modern cities face growing challenges such as excessive land use, rapid urbanization and heavy reliance on private vehicles, leading to high traffic congestion and air pollution, with negative consequences for public health. Rural areas, on the other hand, often suffer from inadequate transport infrastructure and limited mobility options.

In this context, advancements in intelligent vehicle technologies are emerging as a key enabler of sustainable mobility. The integration of Advanced Driver Assistance Systems (ADAS) is transforming transport safety and efficiency, offering real-time monitoring and driver support to mitigate risks. ADAS technologies utilize cutting-edge sensors, data analytics and automation to improve driving behaviour, reduce fuel consumption and minimize environmental impact, thereby contributing to a more sustainable transport network.

Objectives

This study explored the role of advanced simulator technologies in assessing risk factors associated with sustainable mobility in both urban and rural environment. A controlled experimental setup was conducted, leveraging simulator-based methodology to analyze key mobility risks. The research integrates real-world data from vehicles, drivers, road conditions and environmental factors to evaluate potential hazards and enhance transport safety.

The core concept builds upon a Safety Tolerance Zone (STZ) framework, designed to change attitudes and promote safe driving behaviour by continuously assessing task complexity (e.g. traffic, road and weather conditions) and coping capacity (e.g. speeding, headway, distraction, illegal overtaking).

Methodology

Within the framework of this work, a driving simulator experiment was implemented involving 55 drivers and 165 trips across different road environments. Taking into account that targeted risks typically occur in urban and rural areas, three location types were examined: six-lane two-way highways, rural undivided two-lane roads and urban single-lane roads.

The simulator experiment consisted of three consecutive scenarios. Firstly, scenario 1 referred to a reference period in order to monitor driving behaviour, without the use of interventions. Customized interventions in safety-critical situations (i.e. close to the boundary of the STZ) were proposed, including real-time and in-vehicle warnings. Based on this, scenario 2 referred to an intervention scenario influencing driving behaviour with focus on fixed timing thresholds. Lastly, scenario 3 referred to an intervention scenario with modifying condition.

State-of-the-art ADAS technologies, including CardioGateway, CardioWheel/Wearable, Mobileye and other intervention devices, were integrated into the simulator framework. Vehicle data (speed, braking, turn indicators) were collected through Mobileye, which enabled real-time interventions. The collected data was processed via an external controller, converting simulated driving parameters into actionable insights for vehicle safety systems.

To evaluate the impact of interventions, Generalized Linear Models (GLM) and Structural Equation Models (SEM) were applied. GLM was used to identify correlations between driving performance metrics, while SEM was employed to establish relationships between latent (unobservable) and observable risk factors.

Results

Risk levels were assessed using the STZ framework, categorizing driving behaviour into three levels: normal (low risk), dangerous (moderate risk) and avoidable accident (high risk).

Through the application of SEM model, the structural model between the latent variables revealed some interesting results. Firstly, task complexity and coping capacity were inter-related with a negative correlation. This means that as the complexity of a task increases, an individual's coping capacity tends to decrease. This negative correlation highlights the inverse relationship between the difficulty of tasks and the ability to handle stress effectively.

Overall, the structural model between task complexity and risk showed a negative coefficient, which means that increased task complexity relates to decreased risk. This implies that more complex tasks tend to have lower levels of risk. This might be due to the fact that complex tasks often require more detailed planning, careful execution and greater attention to detail, which can mitigate potential risks. Conversely, simpler tasks might carry higher risks due to potential oversight or lack of thorough consideration.

Similarly, the structural model between coping capacity and risk demonstrated a negative coefficient, which means that increased coping capacity relates to decreased risk. This indicates that as coping capacity increases, the associated risk decreases. In other words, drivers with higher coping capacity are generally better at managing and mitigating risks. They are more adept at handling stress and challenges, which enables them to effectively navigate and reduce potential risks. Conversely, those with lower coping capacities may struggle to manage stress and challenges, leading to higher levels of risk.

Discussion and Conclusions

The findings provided valuable insights for policymakers, transport planners and industry stakeholders, highlighting the potential of new vehicle technologies to support the transition toward sustainable mobility in both urban and rural areas. Simulator experiments offer a cost-effective, data-driven approach to evaluate risk factors and design evidence-based interventions.

From a technological perspective, advancements in AI-driven ADAS, multimodal transport solutions and smart urban planning are essential to achieving safe, efficient and environmentally friendly transport networks. The application of simulator-based risk assessment models can inform the development of real-world interventions that improve driving behaviour, reduce congestion and lower emissions.

Lastly, efforts should be made to enhance public awareness and increase the political and social acceptance of transport decarbonization policies. Driver education on the benefits of smart transport technologies could be also promoted. Behavioural adaptation and training programs can complement technological advancements, ensuring that both drivers and automated systems work in synergy to create safer and more sustainable mobility solutions for the future.

Keywords: Safety Tolerance Zone; Sustainable Mobility; Transport Safety; Simulator Experiment.

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