24th European Transport Congress (ETC 2026): Resilient and Reliable Mobility Systems
7-8 May 2026, Vienna, Austria

Analysis of Risk Factors Affecting the Driver Safety Tolerance Zone Using Driving Simulator Data for Enhanced Mobility Resilience

Eva Michelaraki, George Yannis

National Technical University of Athens, Department of Transportation Planning and Engineering, Athens, Greece

Introduction

Insufficient headway, the gap between two vehicles, is a **major contributor to traffic collisions**, as a gap that is too small limits a driver's ability to react to sudden braking. Headway can be expressed in time or distance and maintaining an adequate gap helps drivers manage both physical and cognitive demands by providing time to respond to changing traffic. This reduces stress, cognitive load and supports situational awareness.

Objectives

The aim of this work is to develop a **context-aware Safety Tolerance Zone (STZ),** which defines the point at which self-regulated driving remains safe. The STZ reflects the balance between driving task demands (task complexity) and the driver's ability to cope with them (coping capacity). It includes three phases: normal driving, where crash risk is low and the driver adapts effectively; danger, where changing conditions increase crash risk but a collision is not yet inevitable; and avoidable accident, where a crash is unfolding but corrective action can still prevent it. This study aims to improve driver STZ through the analysis of **road, vehicle and behavioural risk factors**.

Methodology

A **simulator experiment was conducted with 55 participants** and data from 165 trips were collected and analyzed. Key explanatory variables related to risk and the most reliable indicators of task complexity (e.g. weather, time of the day) and coping capacity (e.g. headway, speed) were evaluated, as depicted in Figure 1. Structural Equation Modelling (SEM) was used to test hypotheses about relationships among observed and latent variables.

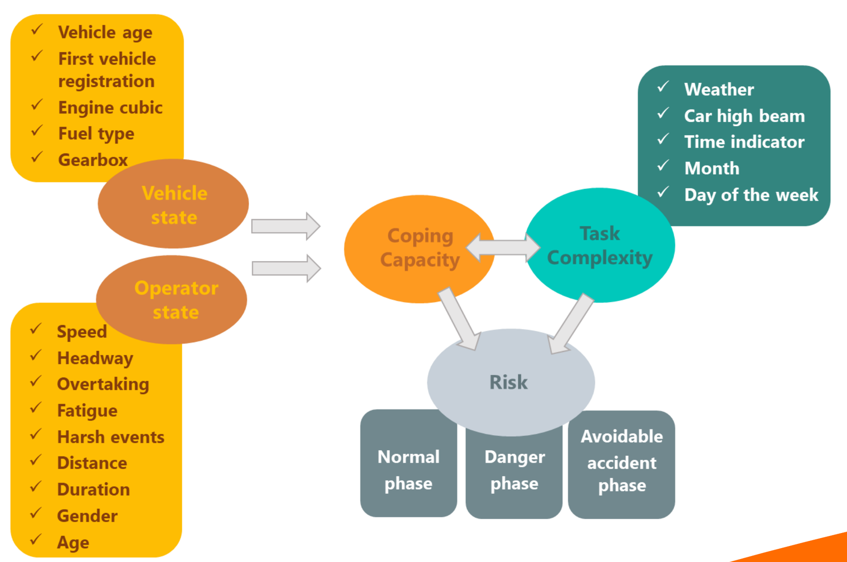

Figure 1: Conceptual framework for risk prediction of task complexity and coping capacity

Results

Risk was assessed using the **three STZ headway levels** (normal driving, dangerous driving and avoidable accident). Task complexity was represented by trip duration and distance travelled, while coping capacity was measured through driver state indicators such as TTC, average speed, hands-on events and fatigue.

Results showed that distance and duration **were positively correlated with task complexity**. Hands-on events and fatigue were positively associated with coping capacity, suggesting that fatigued drivers may adopt more cautious behaviours. In contrast, TTC and average speed were negatively correlated with coping capacity, indicating reduced ability to manage driving demands at longer TTC and higher speeds. SEM findings revealed a **positive relationship between task complexity and coping capacity** (coefficient = 0.14), implying that drivers tend to increase their engagement as task demands rise. Task complexity showed a strong positive association with risk (0.53), whereas coping capacity showed a strong negative association with risk (-4.29), indicating that higher coping ability reduces crash likelihood. The corresponding SEM path diagram is shown in Figure 2.

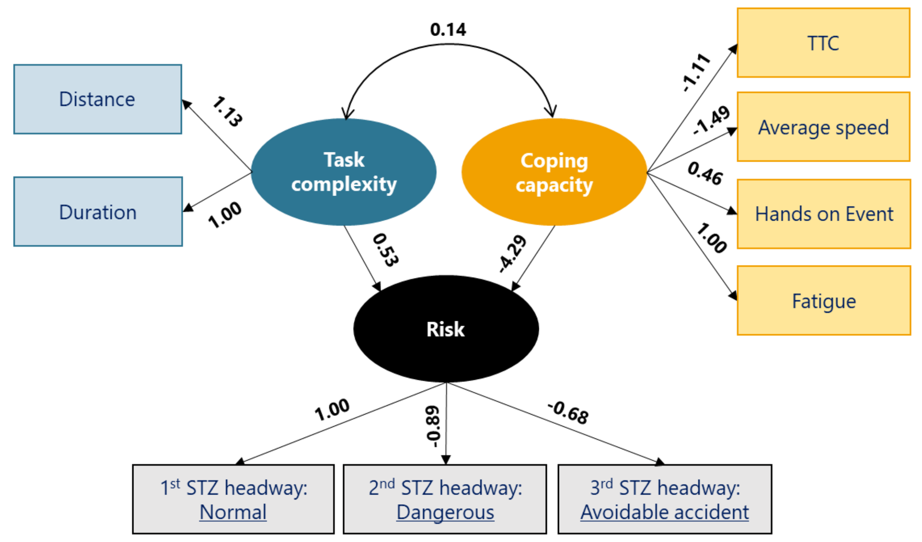

Figure 2: SEM results of task complexity and coping capacity on risk (STZ headway)

SEM revealed that **task complexity significantly increased crash risk**, especially under demanding conditions such as adverse weather, night-time driving or complex environment. In contrast, coping capacity showed a strong negative relationship with crash risk, indicating that drivers with higher coping ability are better equipped to manage challenging situations.

Conclusions

The resulting GFI was 0.973 and AGFI was 0.952, both exceeding the conventional threshold of 0.90, indicating a very good model fit. Additional indices, including the CFI=0.966, TLI=0.944 and RMSEA=0.079, further support the adequacy of the model and confirm the robustness of the latent structure. Table 1 summarizes the model fit of SEM applied for headway, while residual variances details are presented in Table 2.

Table 1: Model Fit Summary for STZ headway

Model Fit measures	Values
CFI	0.966
TLI	0.944
RMSEA	0.079
GFI	0.973
AGFI	0.952
Hoelter's critical N (α = .05)	247.93
Hoelter's critical N (α = .01)	300.04
AIC	65281.04
BIC	65445.96

Table 2: Residual variances STZ headway

Variable	Estimate	Std. Error	z-value	P(>|z|)
Distance	0.108	0.024	4.576	< .001
Duration	0.107	0.023	4.542	< .001
Fatigue	0.950	0.024	39.002	< .001
TTC	0.939	0.025	38.280	< .001
Average speed	0.890	0.026	33.990	< .001
HandsOnEvent	0.989	0.024	40.565	< .001
Headway_STZ_level_0	-0.242	0.059	-4.082	< .001
Headway_STZ_level_1	0.177	0.049	3.652	< .001
Headway_STZ_level_2	0.422	0.029	14.344	< .001

The analysis also showed a positive relationship between task complexity and coping capacity, suggesting that drivers tend to **become more engaged and adaptive when confronted with complex driving tasks**. Although coping capacity helps reduce crash likelihood, task complexity exerted a stronger overall influence on risk. A positive association between risk and STZ indicators was also observed, with the highest values appearing during normal driving, highlighting the dynamic nature of risk perception even in seemingly safe conditions.

Overall, the study offers a **holistic view of driver safety by integrating driver, vehicle and environmental factors** within a unified mobility resilience framework. The STZ proved effective for understanding how drivers respond to changing task demands and coping requirements. Future work with larger, more diverse datasets could improve the generalisability and applicability of this approach.

Acknowledgments

The research was funded by the EU H2020 i-DREAMS project (Project Number: 814761) funded by European Commission under the MG-2-1-2018 Research and Innovation Action (RIA).

Contact Information:
Eva Michelaraki, PhD, Research Associate NTUA,
Email: evamich@mail.ntua.gr