Interactions among Road, Vehicle and Driver Risk Factors for the Identification of Safety Tolerance Zone

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Introduction

Road safety is a **complex issue** influenced by a wide range of factors, including driver characteristics, environmental conditions and traffic variables.

Driver characteristics, such as speeding, distraction, impaired driving, aggressiveness and non-compliance with traffic regulations can increase crash risk. In addition, the condition and safety **features of vehicles** also play a critical role in averting crashes and reducing the likelihood of serious injuries. Similarly, **environmental conditions**, such as adverse weather conditions, poor visibility and uneven road surfaces can increase the likelihood of crashes.

Objective

The aim of this work was to investigate the **interactions among road environment, vehicle state and driver behavior** and their impact on crash risk. The fundamental challenge within this research is how explanatory variables (i.e. performance metrics and indicators of task complexity and coping capacity) are correlated with the dependent variable risk in order to predict STZ levels.

Data Collection

A **naturalistic driving experiment** was conducted, involving a total of 135 drivers aged 20-65. The most prominent driving behavior indicators, such as speeding, headway, duration, distance and harsh events were assessed, as depicted in Figure 1.

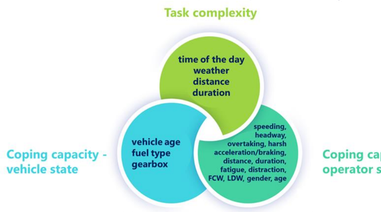

Figure 1: *Variables of task complexity and coping capacity*

An **integrated set of state-of-the-art technologies** were utilized to monitor driving performance factors. The technology described in Figure 2 measures the environment, vehicle and driver indicators used to define task complexity and coping capacity in order to calculate which phase of the STZ the driver is operating within.

Figure 2: *Technologies to monitor driver, environment and vehicle state*

Methodology

- ✓ **Generalized Linear Models (GLMs)** were applied to investigate the relationship between speeding and several explanatory variables of task complexity and coping capacity (both vehicle and operator state).
- ✓ **Structural Equation Models (SEMs)** were used for modeling complex and multi-layered relationships between observed and unobserved variables.
- ✓ **Goodness-of-Fit measures** (AIC, BIC, CFI, TLI, RMSEA) were assessed for the model selection.

Regression Analyses (GLM)

The dependent variable of the developed model was the **dummy variable "speeding",** coded with 1 if there was a speeding event and with 0 if not. For task complexity, the variables used were time indicator and wipers. With regards to coping capacity - vehicle state, the variables used were fuel type, vehicle age and gearbox, while for coping capacity - operator state, the variables used were duration, distance travelled, harsh acceleration/braking, gender and age, as shown in Table 1.

Table 1: *Parameter estimates and multicollinearity diagnostics of the GLM*

Variables	Estimate	Std. Error	z-value	Pr(|z|)	VIF
(Intercept)	-0.618	0.004	-162.415	< .001	-
Time indicator	0.033	0.002	15.172	< .001	1.154
Weather	0.058	0.008	7.609	< .001	1.007
Fuel type - Diesel	-5.904	1.863	-3.169	0.002	4.548
Vehicle age	1.212	2.009	60.317	< .001	3.482
Gearbox - Automatic	-1.231	2.321	-5.302	< .001	2.175
Duration	5.123	2.900	17.664	< .001	1.111
Distance	1.820	8.235	22.096	< .001	1.091
Harsh acceleration	8.358	2.222	37.609	< .001	2.892
Harsh braking	5.776	2.055	28.104	< .001	2.883
Gender - Female	-3.295	1.813	-1.818	0.069	1.555
Age	-1.210	2.285	-52.977	< .001	4.062
Summary statistics					
AIC	1.231x10+6				
BIC	1.051x10+6				
Degrees of freedom	822174				

The indicators of **task complexity**, such as time indicator and wipers were positively correlated with speeding. It was found that higher speeding events occurred at night compared to during the day. This may be due to fewer cars on the road, lower visibility, and a false sense of security that comes with driving in the dark. Regarding the indicators of **coping capacity – vehicle state**, vehicle age was found to be positively correlated with speeding, meaning that as vehicles get older, the likelihood of speeding incidents increases. On the other hand, fuel type and gearbox were negatively correlated with speeding.

It was demonstrated that indicators of **coping capacity – operator state**, such as duration, distance travelled, harsh acceleration/braking had a positive relationship with speeding. Taking into consideration socio-demographic characteristics, results revealed that the vast majority of male drivers displayed less cautious behavior during their trips and exceeded more often the speed limits than female drivers. Young drivers appeared to have a riskier driving behavior than older drivers and were more prone to exceed the speed limits.

Latent Analyses (SEM)

Risk was measured by means of the STZ levels for speeding (level 1 refers to 'normal driving' used as the reference case; level 2 refers to 'dangerous driving' while level 3 refers to 'avoidable accident driving'). The latent variable of task complexity was measured by means of the environmental indicators of time of the day and weather as well as exposure indicators, such as trip duration and distance travelled. The latent variable of coping capacity was measured by means of both vehicle and operator state indicators, such as vehicle state, gearbox, fuel type, gender and headway.

Results revealed that **higher task complexity led to higher coping capacity** by the vehicle operators. It was found that when drivers encountered complex tasks, such as driving during risky hours (22:00-05:00) or adverse weather conditions, they were compelled to engage more deeply with the driving process and tended to regulate well their capacity to react to potential difficulties, while driving.

Task complexity was positively correlated with risk, as drivers could become overwhelmed by the demands of complex tasks, leading to reduced attention to the road and other traffic participants. On the other hand, **coping capacity was negatively correlated with risk**. For instance, vehicle age, gearbox, gender and driver's age were negatively correlated with coping capacity. This suggests that older vehicles, the type of gearbox and certain gender and age drivers' demographic characteristics were associated with a decreased ability to manage or respond to driving demands and challenges effectively.

Table 2: *Model Fit Summary for speeding for the different experiment phases*

Model Fit measures	Phase 1	Phase 2	Phase 3	Phase 4	Total
	Values				
CFI	0.927	0.822	0.898	0.903	0.920
TLI	0.897	0.761	0.863	0.870	0.893
RMSEA	0.100	0.158	0.108	0.110	0.095
GFI	0.940	0.874	0.918	0.913	0.932
Hoelter's critical N (α = .05)	246.410	256.591	320.534	315.308	253.706
Hoelter's critical N (α = .01)	269.362	264.409	337.344	331.383	275.180

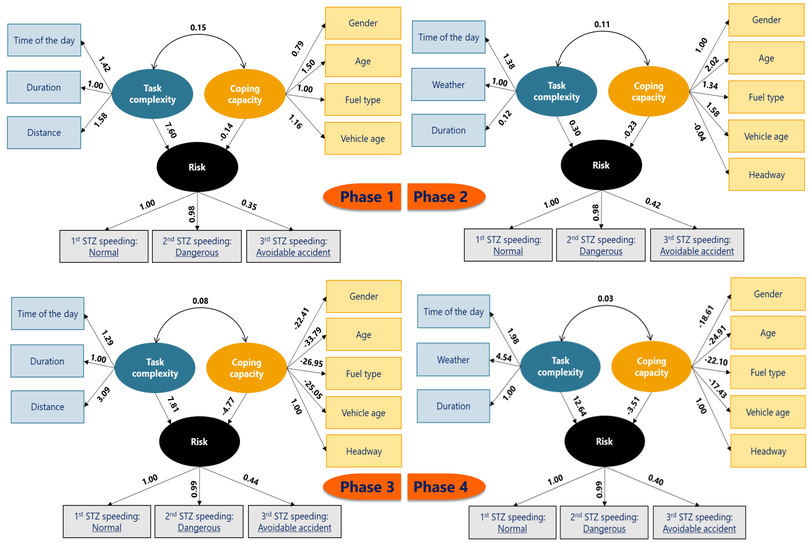

Figure 3: *SEM results of task complexity and coping capacity on risk (STZ speeding) - Experiment phase 1 (monitoring), 2 (real-time interventions), 3 (real-time & post-trip interventions), 4 (real-time, post-trip interventions & gamification)*

It was observed that the measurement equations of task complexity and coping capacity were **fairly consistent among the different phases**. At the same time, the loadings of the observed proportions of the STZ of speeding were consistent among the different phases. The structural model between task complexity and risk were positively correlated among the four phases, while coping capacity and risk found to have a negative relationship in all phases of the experiment.

Conclusions

- ❖ Given that SEM deals with latent concepts, and both task complexity and coping capacity are latent constructs, this **approach was the most appropriate** and constituted the key component of the statistical analysis in this study.
- ❖ It was revealed task complexity and risk were **positively correlated** in all phases of the experiment, which means that increased task complexity relates to increased risk.
- ❖ On the other hand, coping capacity and risk found to have a **negative relationship** in all phases, which means that increased coping capacity relates to decreased risk
- ❖ Both **real-time and post-trip interventions** had a positive influence on risk, increasing drivers' coping capacity and reducing dangerous driving behavior.
- ❖ Understanding and modeling the interrelationship between task complexity, coping capacity and crash risk is vital for developing **targeted interventions and countermeasures** to enhance traffic safety and reduce crash risk on roadways.
- ❖ This includes **improving road infrastructure**, implementing appropriate signage and road markings, educating drivers about the impact of task complexity on their performance and promoting the development of coping strategies to manage complex driving situations.
- ❖ **Technological advancements in vehicle automation and driver assistance systems** can also play a role in mitigating crash risk by reducing the cognitive load associated with complex tasks and providing support to drivers in challenging driving conditions.

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