Implementation of an integrated model for understanding the impact of task complexity and coping capacity on crash risk

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Introduction

- Driving is a dynamic control task where the driver should extract relevant information from numerous visual signs, make decisions and perform control actions, all influenced by their expectations and observations

- The driving task is influenced both by external environmental factors and by the driver's own perception, planning and ability to handle challenging conditions

- The difficulty of driving in a given context is determined by road, traffic, vehicle and behavioural indicators, which together define the demands placed on the driver

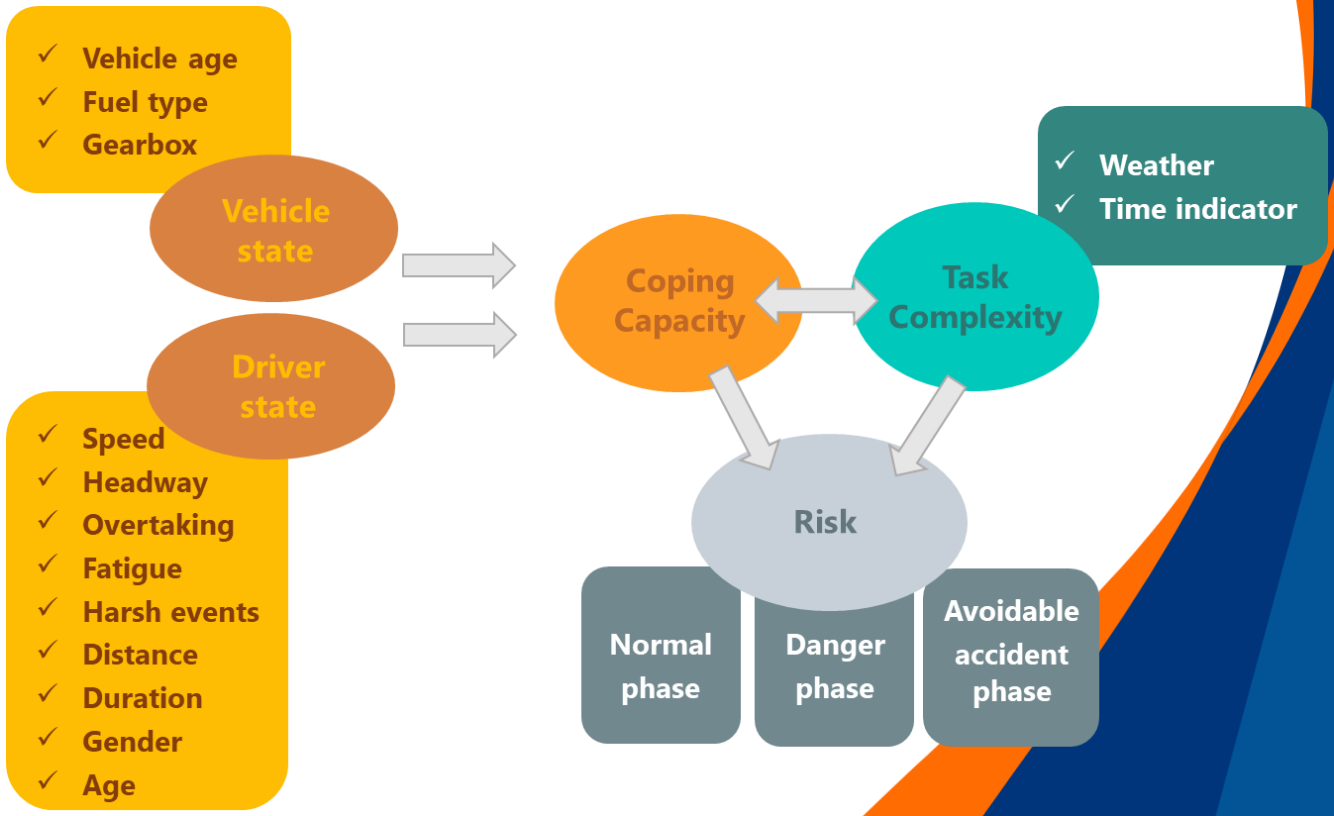
Data Overview

- 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 relates to the current status of the real world context in which a vehicle is being operated:
  - road layout (i.e. highway, rural, urban)
  - time and location
  - traffic volumes (i.e. high, medium, low)
  - weather conditions
- Coping capacity is dependent upon two underlying factors and it consists of several aspects:
  - vehicle state (e.g. technical specifications, current status)
  - driver state (e.g. behaviour, sociodemographic profile)

Task complexity	Coping capacity - vehicle state	Coping capacity - operator state		Risk
Car wipers	Vehicle age	Distance	Inter Beat Interval	Headway map levels
Car high beam	First vehicle registration	Duration	Headway	Speeding map levels
Time indicator	Fuel type	Average speed	Overtaking	Overtaking map levels
Distance	Engine Cubic Centimeters	Harsh acceleration/ braking	Fatigue	Fatigue map levels
Duration	Engine Horsepower (HP)	Forward collision warning (FCW)	Gender	Harsh acceleration
Month	Gearbox	Pedestrian collision warning (PCW)	Age	Harsh braking
Day of the week	Vehicle brand	Lane departure warning (LDW)	Educational level	Vehicle control events

Objectives

- Development of an integrated model to identify the impact of task complexity and coping capacity on crash risk
- Investigation of how explanatory variables of **task complexity** (e.g. time of the day, weather conditions) and **coping capacity** (e.g. fuel type, vehicle age, speeding, harsh events) are correlated with the dependent variable of risk in order to predict STZ levels



Experimental Design

Naturalistic driving experiment:

- 135 drivers, aged 20-65
- 31,954 trips across different road environments
- 4 months

The naturalistic experimental design has been subdivided into four consecutive phases:

- **Phase 1:** monitoring (baseline measurement)
- **Phase 2:** real-time intervention
- **Phase 3:** real-time intervention and post-trip feedback
- **Phase 4:** real-time intervention and post-trip feedback and gamification

Methodology

- Explanatory analyses such as Generalized Linear Models (GLM) were performed to examine key correlations among driving performance metrics

- Latent analyses such as Structural Equation Models (SEM) were employed to establish relationships between observable risk factors (i.e. number of speeding events) and latent or unobserved variables (i.e. crash risk)

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

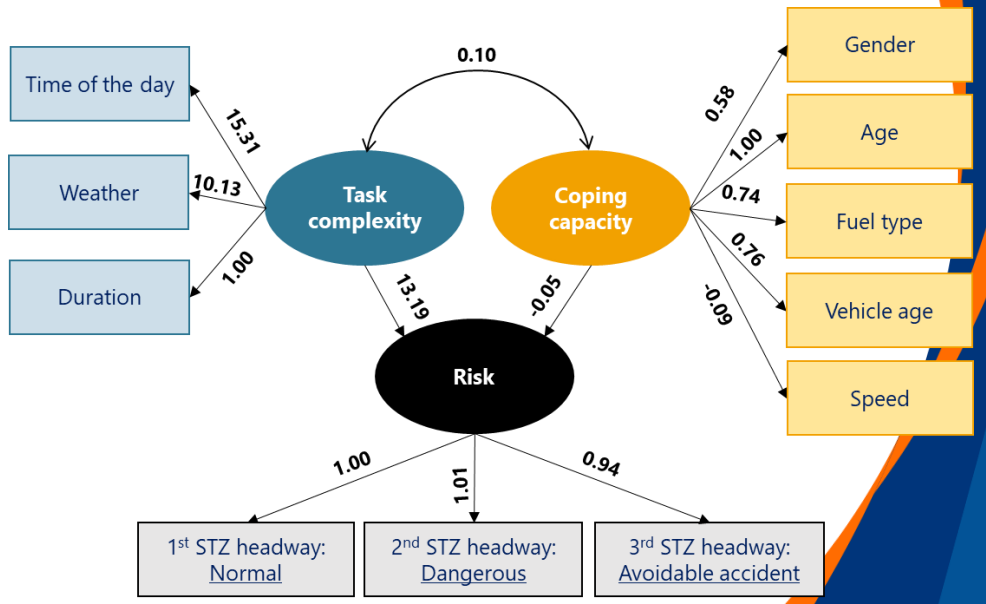
Generalized Linear Model Results

- Time of the day was negatively correlated with headway, which means that drivers tend to keep safer distances from the vehicle in front of them during the night
- The wipers variable found to have a positive correlation with headway, indicating that there are more headway events during adverse weather conditions
- Vehicle age had a positive relationship with headway, indicating that as the vehicle age increases, the likelihood of headway events also increases
- Indicators of coping capacity - driver state, such as duration, harsh acceleration, harsh braking and average speed had a positive impact on headway
- Taking into account socio-demographic characteristics, gender was negatively correlated with headway, suggesting that female drivers perform fewer headway events and tend to be more cautious in maintaining following distances compared to male drivers
- On the other hand, age was positively correlated with headway, indicating that older drivers tend to have more headway events, maybe due to slower reaction times

Variables	Estimate	Std. Error	z-value	Pr(|z|)	VIF
(Intercept)	-0.339	0.003	-14.275	< .001	-
Time indicator	-4.713	1.527	-3.086	0.002	1.001
Weather	-0.059	0.007	-2.852	< .001	1.003
Fuel type - Diesel	-3.432	1.906	-8.094	< .001	3.888
Vehicle age	3.194	1.601	9.942	< .001	4.765
Gearbox - Automatic	-5.122	1.213	-4.032	0.003	2.851
Duration	8.283	3.969	19.871	< .001	1.279
Harsh braking	5.707	2.456	32.562	< .001	3.396
Harsh acceleration	4.590	2.201	25.239	< .001	3.404
Average speed	7.686	5.019	36.273	< .001	1.103
Gender - Female	-2.097	1.349	-2.775	< .001	1.495
Age	3.764	1.879	3.203	< .001	6.119

Structural Equation Model Results (1/2)

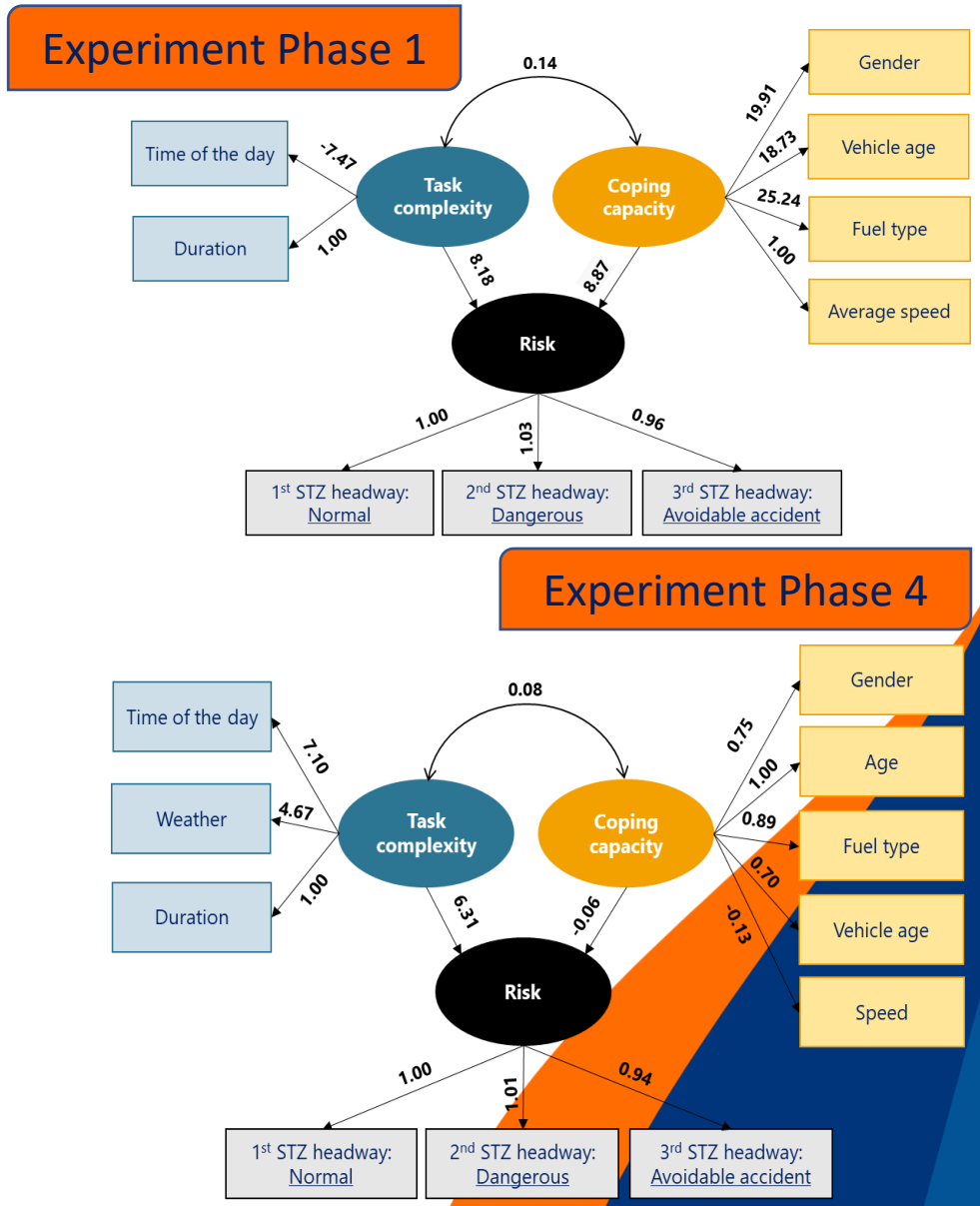
- The latent variable risk is measured by means of the STZ levels for headway (level 1 refers to 'normal driving' used as the reference case, level 2 refers to 'dangerous driving' while level 3 refers to 'avoidable accident driving')
- Task complexity and coping capacity are inter-related with a positive correlation, implying that drivers coping capacity increases as the complexity of driving task increases
- Task complexity and risk shows a positive coefficient, which means that increased task complexity relates to increased risk
- On the other hand, the structural model between coping capacity and risk shows a negative coefficient, which means that increased coping capacity relates to decreased risk



Model Fit measures	Value
CFI	0.945
TLI	0.927
RMSEA	0.106
GFI	0.921
Hoelter's critical N (α = .05)	224.059
Hoelter's critical N (α = .01)	241.364
AIC	2.043×10+7
BIC	2.043×10+7

Structural Equation Model Results (2/2)

- Higher task complexity was associated with an **increased crash risk** in all phases, as drivers could probably become overwhelmed by the demands of complex tasks
- The loadings of the observed proportions of the STZ of headway **are not consistent among the different phases**, as slight differences were observed among phases
- **Coping capacity and risk** found to have a positive relationship in phases 1 and 2 of the experiment and a negative relationship in phases 3 and 4
- Drivers with limited coping capacity may **struggle to effectively manage complex tasks**, leading to higher crash risk



Discussion

- Safety interventions were evaluated in terms of their effectiveness in keeping the driver within safe boundaries (i.e. STZ) by monitoring and collecting data on driving behaviour
- Both real-time and post-trip interventions positively influenced risk compensation, increased drivers' coping capacity and reduced dangerous driving behaviour
- When safety interventions were introduced during different phases of the experiment, drivers improved their performance and became more aware, which led to greater headways and fewer harsh events
- Personalised feedback and targeted interventions for high-risk groups are essential to enhance coping capacity and reduce crash risk in real-world driving conditions

Conclusions

- High task complexity, such as navigating through heavy traffic, adverse weather conditions or unfamiliar routes, demands increased cognitive workload, quick decision-making and heightened alertness
- When drivers have a high coping capacity, they can manage these challenges more effectively, maintaining their actions within a Safe Tolerance Zone
- However, if the coping capacity is low, the driver may struggle to handle these complexities, leading to increased stress and tension levels that push their actions outside the STZ
- High task complexity combined with low coping capacity results in significantly higher crash risk, as the driver is more likely to operate outside the STZ, potentially negatively affecting driving performance and safety

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