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Modeling the concept of a Safety Tolerance Zone: State-of-the-art & proposed alternatives

Eva Michelaraki
Transportation Engineer, PhD Candidate

Together with:
Christos Katrakazas, Amir Pooyan Afghari, Eleonora Papadimitriou, Kui Yang, Christelle Al Haddad, Constantinos Antoniou, Tom Brijs and George Yannis

TU Delft · Technische Universität München · UHASSELT

The i-DREAMS project

- 13 Project partners:
  - National Technical University of Athens

    Universiteit Hasselt, Loughborough University, Technische Universität München, Kuratorium für Verkehrssicherheit, Delft University of Technology, University of Maribor, OSeven Telematics, DriveSimSolutions, CardioID Technologies, European Transport Safety Council, POLIS Network, Barraqueiro Transportes S.A.

- Duration of the project:
  - 48 months (May 2019 – April 2023)

- Framework Program:
  - Horizon 2020 - The EU Union Framework Programme for Research and Innovation - Mobility for Growth

Introduction

- Within a transport system, a driver can be viewed as a (technology assisted) human operator, self-regulating control over a vehicle in the context of crash avoidance

- Safe driving can be regarded as the practice of using driving strategies that minimize the risk and help avoiding critical events (e.g. crashes) by predicting hazardous situations on the road

- Dangerous driving is found when an individual's driving falls below the expected level of a careful and competent driver

- Road traffic safety can be understood as the result of the safe interaction of participants between themselves and the environment

- When assessing the traffic safety on the road environment, driver's physiological and psychological capabilities should be taken into consideration

Background

- The i-DREAMS project aims to establish a framework for the definition, development, testing and validation of a context-aware safety envelope for driving in a Safety Tolerance Zone (STZ), within a smart Driver, Vehicle and Environment Assessment and Monitoring System

- Taking into account driver background factors and risk indicators associated with driving performance as well as the driver state and driving task complexity parameters, a continuous real-time assessment is made in order to monitor and determine if drivers are within acceptable boundaries of safe operation

- Delayed safety-oriented interventions and post-trip feedback are provided so as to enhance driver’s knowledge, attitudes and perceptions

Safety Tolerance Zone Concept

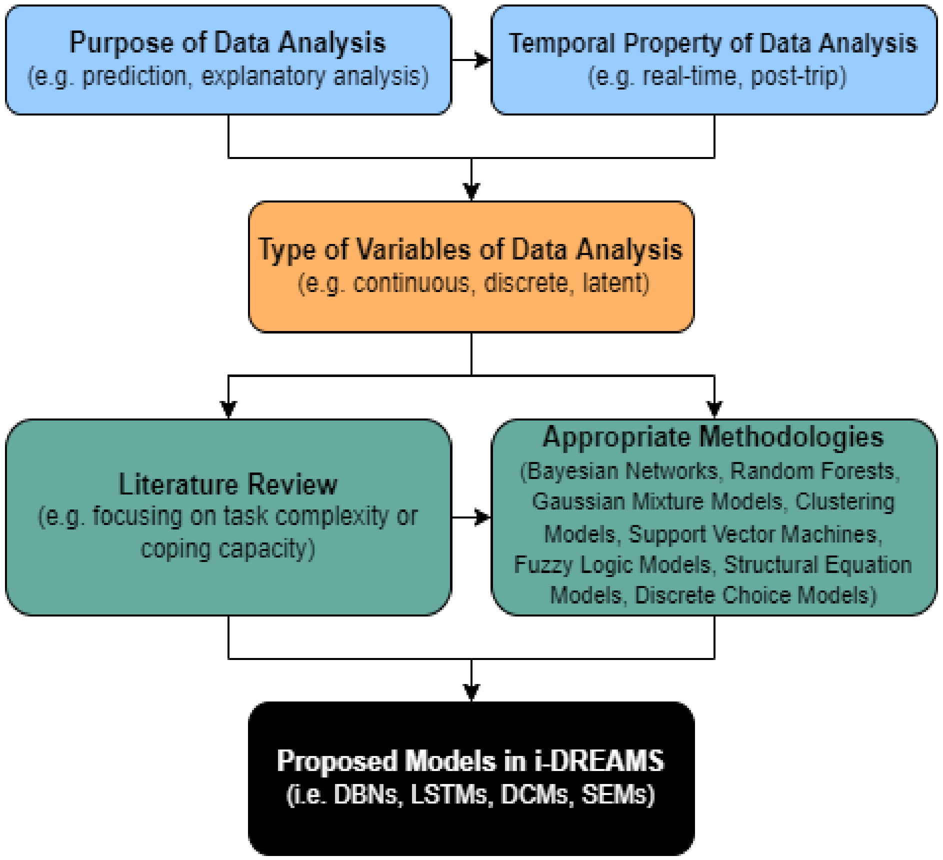
The concept of the STZ is the core concept of the i-DREAMS project and attempts to describe the point at which self-regulated control is considered safe. The STZ is subdivided in three levels of safety:

- Normal Driving phase represents the conditions in which a crash is unlikely to occur, i.e. the crash risk is low. During this phase, drivers can successfully adapt their behaviour in order to meet the task demand
- Danger phase is characterized by changes in normal driving that indicate that a crash may occur, therefore, the crash risk is increased
- Avoidable Accident phase occurs when a collision scenario develops but there is still time for the driver to intervene and avoid the crash. The need for action is more urgent than in the Danger phase and if the driver does not adapt their behaviour to the current circumstances, a crash is very likely to occur

Phases of STZ	Description
Normal Driving phase	Crash risk is minimal
Danger phase	Risk of crash increases as internal or external events occur
Avoidable Accident phase	Crash is very likely to occur if no preventative action taken by driver

Methodology

- Predicting driving behavior by employing mathematical driver models, obtained directly from the observed driving-behavior data, has gained much attention
- In order to obtain the most suitable modeling approaches for the STZ, a thorough literature review of models dealing with driver behavior and collision risk, both in real-time and post-trip, was implemented
- Several state-of-the-art methodological approaches that enable the modeling of crash risk were evaluated
- Specialized machine learning and statistical algorithms were examined in order to relate driving performance with the probability and the severity of a crash, among which four methods have been selected to be used in i-DREAMS



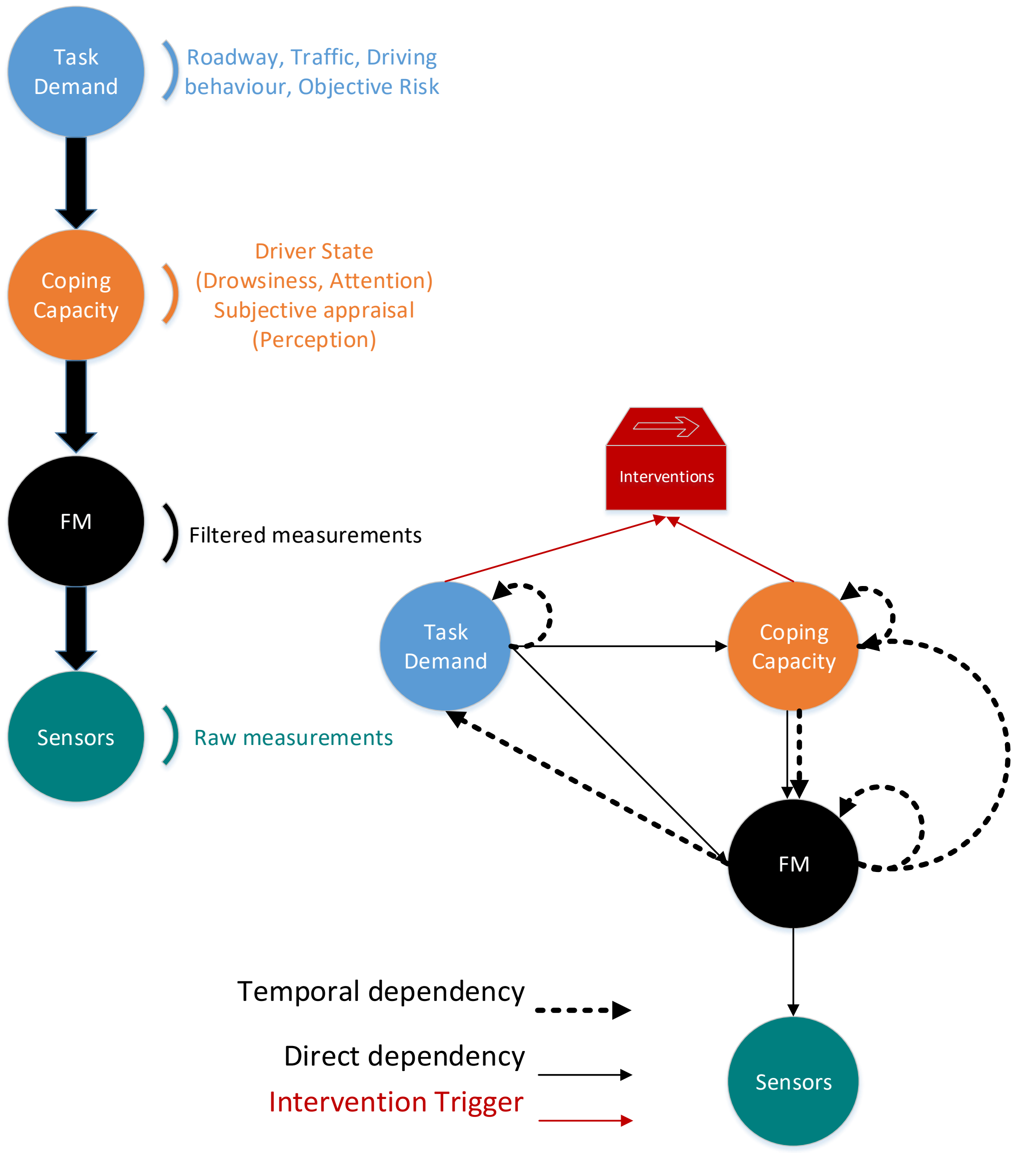
Dynamic Bayesian Networks

- Dynamic Bayesian Networks (DBNs) are the most appropriate method to model **discrete indicators of risk**

- The variables monitored by the i-DREAMS platform concerning **task complexity and coping capacity** (i.e. driver and vehicle state); thus, the raw sensor measurements are observed

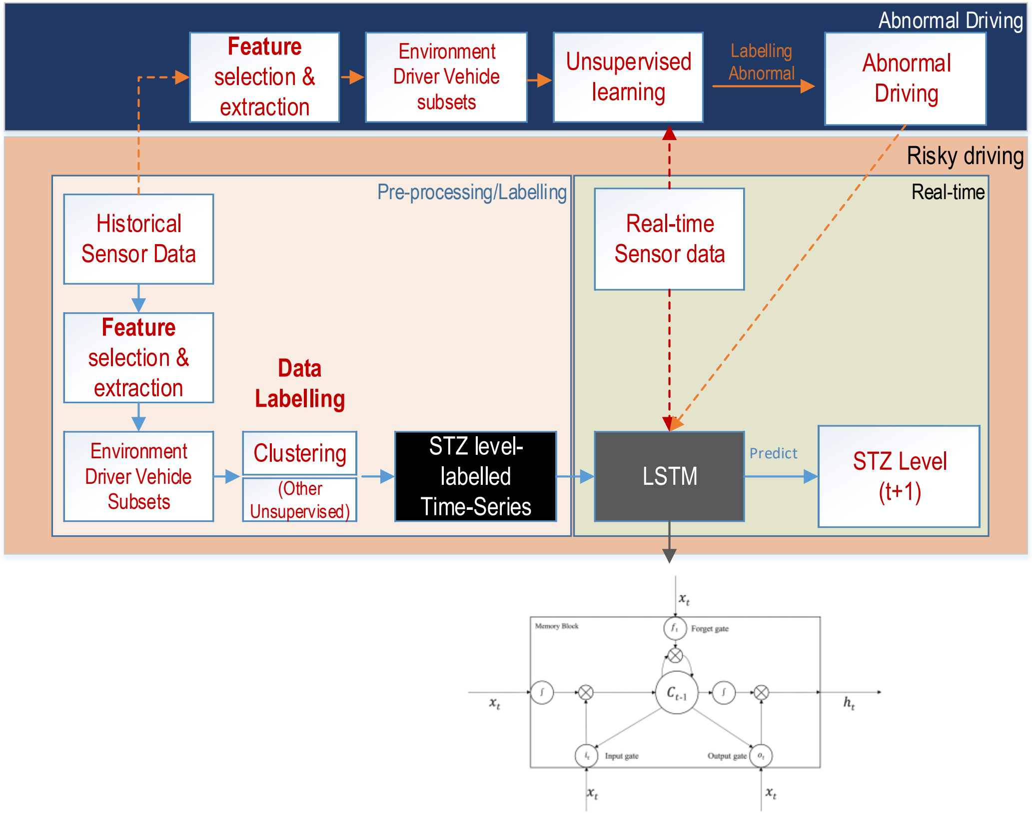
- By filtering these raw measurements, the **Context-Operator-Vehicle (COV)** indicators become available, so they are used to determine the coping capacity and task complexity at each time moment

- As the coping capacity indicates the ability of the driver to **operate safely** with regards to the task imposed, the operator's capacity depends on the complexity of the task



Long Short-Term Memory Networks

- Long Short-Term Memory Networks (LSTMs) are suitable for continuous indicators of risk and they work tremendously well on a large variety of problems
- LSTMs use “memory block” in the hidden unit to capture the long-term dependencies that may exist in the data
- This memorizing capability of LSTM has shown the best performance across many time-series tasks
- The problem of defining the STZ levels becomes more straightforward, since LSTMs as a sub-category of Deep Neural Networks act like “black-boxes” and the only input that needs to be provided to the model are labelled time series data



Discrete Choice Models

- Discrete Choice Models (DCMs) are the most common statistical approaches to model **discrete indicators of risk**
- The first step in formulating DCMs is **defining a utility** for each discrete alternative
- Depending on the **nature of the discrete variable** being nominal (e.g. occurrence of a rare event/no rare event) or ordered (i.e. STZ levels), DCMs can take the form of:
  - Unordered Discrete Choice Models
  - Ordered Discrete Choice Models

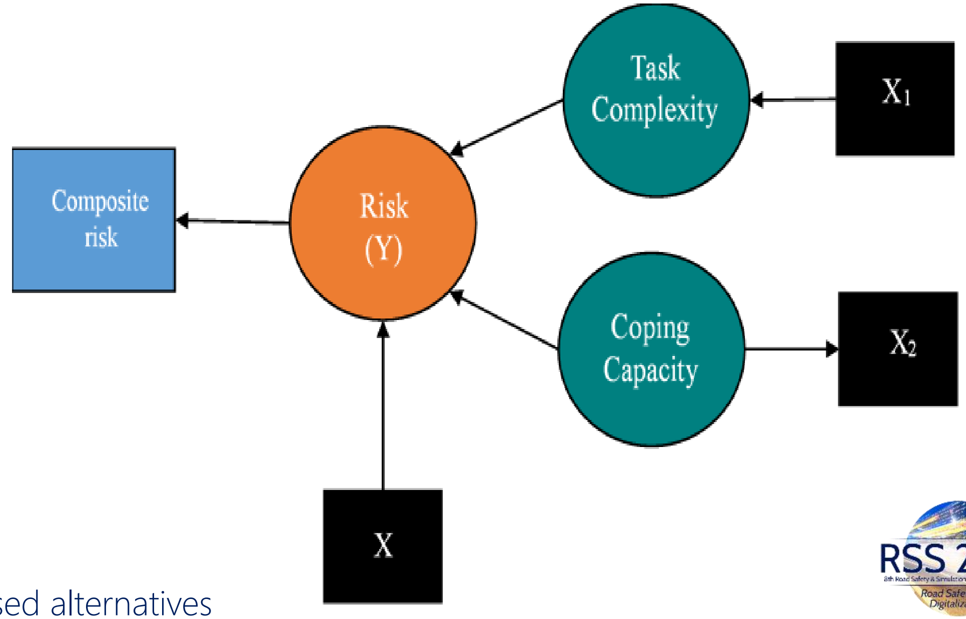
Structural Equation Models

- Structural Equation Models (SEMs) are suitable for continuous indicators of risk which are designed to deal with several difficult modelling challenges, including cases in which some variables of interest are unobservable or latent

- SEMs have two components: a measurement model and a structural model:
  - the measurement model is used to determine how well various observable exogenous variables can measure the latent variables, as well as the related measurement errors
  - the structural model is used to explore how the model variables are inter-related, allowing for both direct and indirect relationships to be modelled

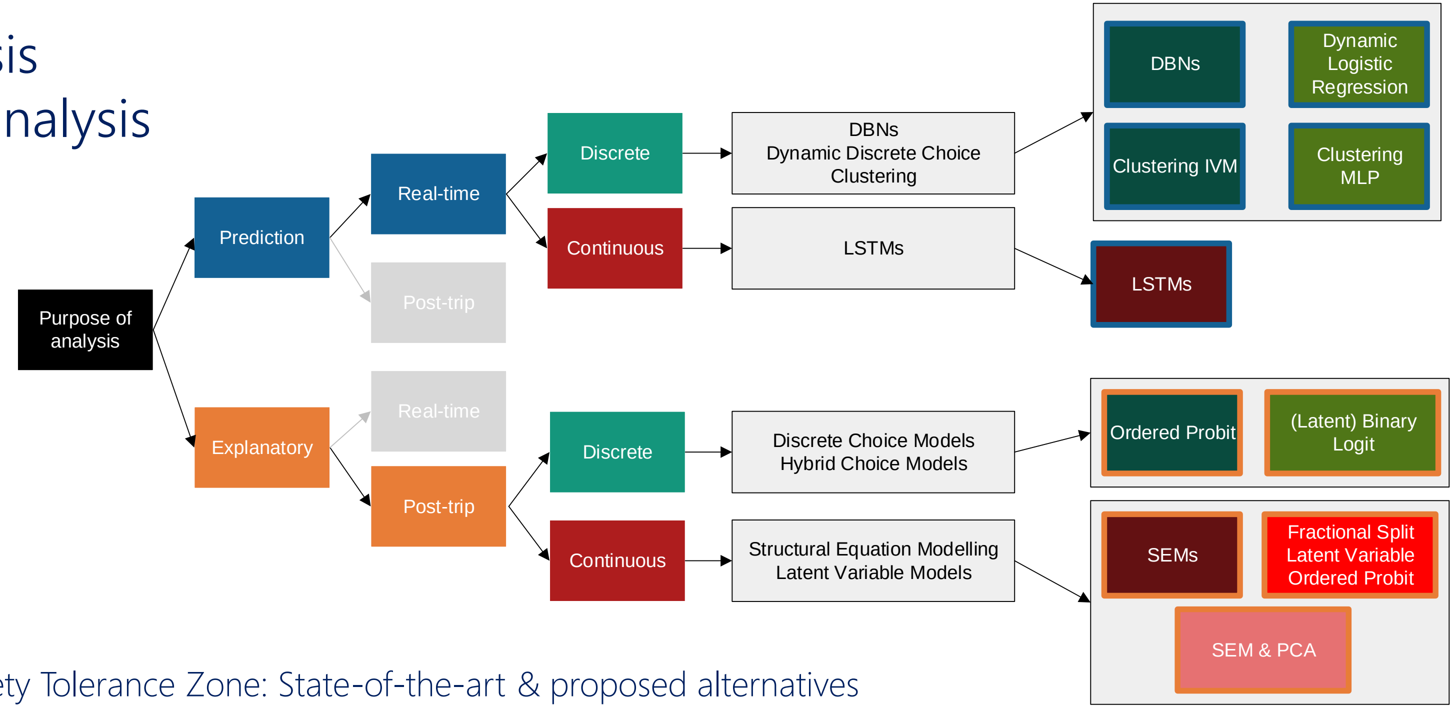
- According to the i-DREAMS concept of the STZ, the latent risk is measured by a composite variable consisting of all risk factors and latent task complexity and latent coping capacity predict the latent risk

- Latent task complexity and latent coping capacity are also measured by observed indicators



Discussion

- When the purpose of data analysis is the prediction of risk (e.g. prediction of the STZ phases), the data should be analyzed in real-time because the predictions in i-DREAMS aim to provide the basis for triggering (real-time) in-vehicle interventions
- When the purpose of data analysis is explanatory analysis, the data should be analyzed after the trip has been completed, because the explanatory analysis in i-DREAMS is primarily done for identifying relationships between driving behavior (at an aggregate level) and risk
- The mathematical model to be used in i-DREAMS depends on a combination of three dimensions:
  - the purpose of data analysis
  - the time element of data analysis
  - the variable type of risk



Future Insights

- For all the proposed approaches, a labelled dataset is needed for training and this should be taken into consideration for the data collection
- The testing, calibration and enhancement of the mathematical models during the i-DREAMS simulation and on-road experiments can assure a sufficient and efficient data analysis, as well as timely initiation of the safety interventions
- When preliminary results are available, the most crucial risk indicators of task complexity and coping capacity will be extracted, the proposed models will be tested and the most suitable models will be selected for data analysis

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