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Modelling hydrogen vehicles road tunnel accidents using a Bayesian Network

Frank Markert, DTU

Introduction
BBN model

The objective is to develop a probabilistic model to assess the probability of accidents leading to release of the on-board stored hydrogen.

- Bayesian Believe Network (BBN) probabilistic road tunnel model
- BBN is used to model potential accident scenarios of hydrogen vehicles in road tunnels.
- Scenarios leading to pressure vessel destruction
- The assessment of the endpoints of these accidents are chosen to be:
  - Scenarios leading to jet fires – immediate ignition
  - Flash fires and explosions – delayed ignition
- Decision support: modelling safety measures:
  - Preventive measures to reduce the number of events
  - Mitigative measures to reduce the potential harm

The Risk Scenario
Tunnel layout

- The specific characteristics of road tunnels are defined by:
  - Materials of the tunnel walls
  - Geometry and size of the tunnel
  - Slope of tunnel , e.g.
    - flat –casted sub-sea tunnels (only ends have a slope)
    - “circular” – drilled sub-sea tunnels (continuous slope deepest point in the middle)
    - increasing slope – e.g. mountains
    - etc.
- A road tunnel tube may be utilized as:
  - one-way directional traffic – 1 or 2 lanes
  - two-way directional traffic - 2 lanes
  - other (more complex situations (crossings, etc.)

The Risk Scenario

Traffic regulation & tunnel safety

- Built-in prevention and mitigation systems,
  - Traffic regulations (number of cars in tube)
  - Distance between vehicles
  - Speed limits
  - Radio communication
  - Traffic control by police
  - etc.
- Evacuation plans and rescue
  - Egress paths
  - Lightening and signs supporting egress
  - Ventilation strategy
  - Shelters
  - Extinguishing materials
  - Emergency calls
  - Emergency service
  - other

The Risk Scenario
Traffic

Type of traffic expected in the tunnel:

- Vehicle types
  - Small , medium, large cars,
  - Professional vehicles: Vans, heavy truck (long distance)
  - Busses
  - Hazardous goods transport.
- Number of vehicles in tunnel
- Fraction of vehicle types

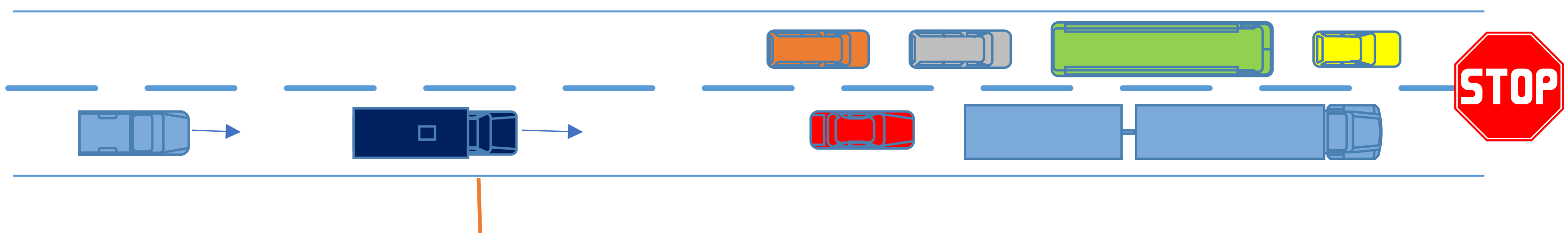
The vehicle types may be driven by traditional fuels, batteries electric vehicles or hydrogen & fuel cell electrical vehicles

Assumption: vehicle crashes into a hydrogen fueled car

Tunnel accidents
Collision scenarios

Many collision scenarios are possible

- ➢ Damage level of the vehicles after collision is dependent on:
  - The velocity differences between the crashing vehicles
  - The respective total mass of the vehicles crashing
  - The orientation of the crash
- ➢ Statistically are accidents most frequent close to tunnel entrance / exit
  - This part of a tunnel is still influenced by weather condition
  - The lightning is changing quickly



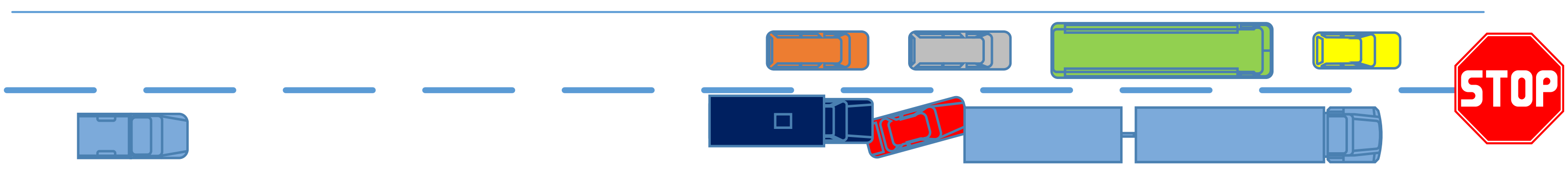
Break point

One possible worst case scenario:
Traffic is stopped due to cueing

Tunnel accidents

Tunnel vehicle crash scenarios

- The tunnel layout is one directional traffic in the tunnel tube. Two lanes.
- Front – rear crashes
- Front – side crashes
- Single driver accidents



Tunnel accidents
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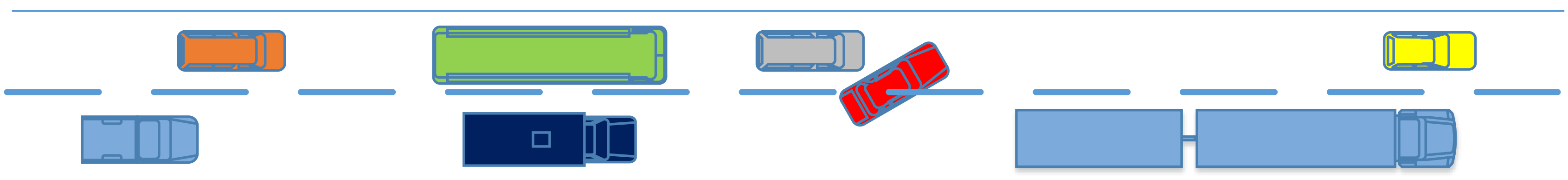

Tunnel accidnts

Tunnel vehicle crash scenarios

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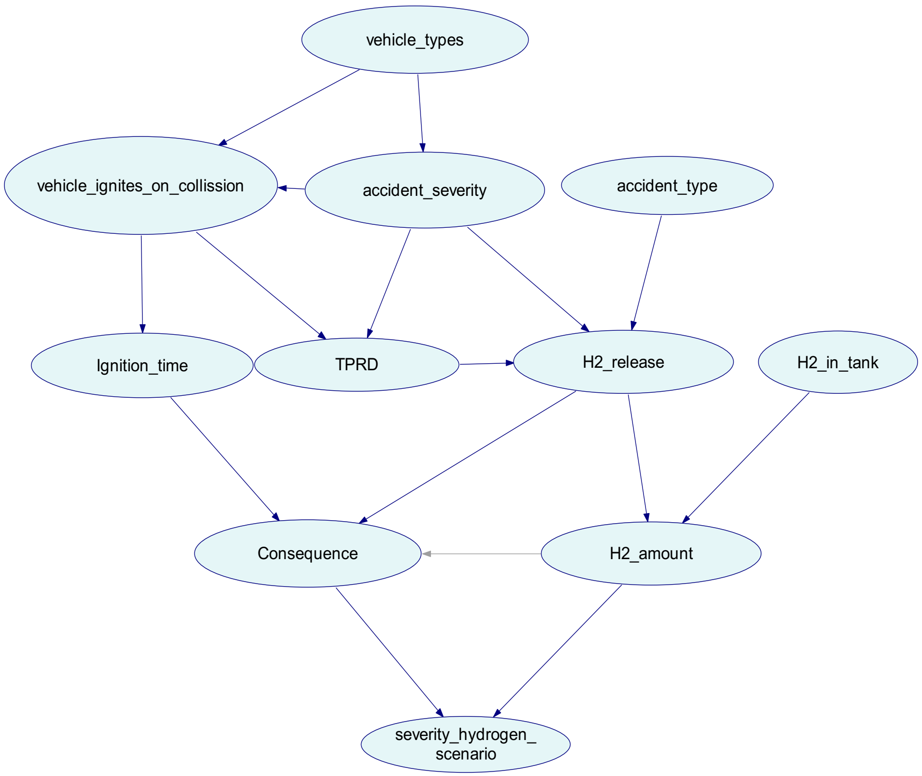
BBN model
Node view



This first approach takes the following key-items into account to predict the conditional probabilities within the BBN

Vehicle types

Accident types

Hydrogen storage size

Consequence types depend on:

- Ignition time
- H2 release & amount

Severity of hydrogen scenarios depend on:

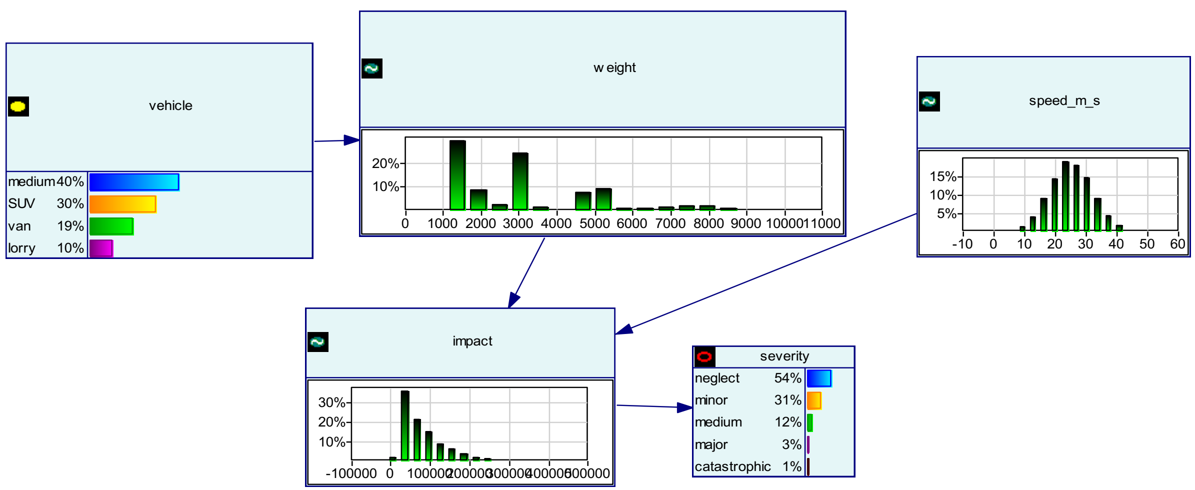
- consequence type
- H2 amount released

BBN hybrid model

Collision severity – alternative approach

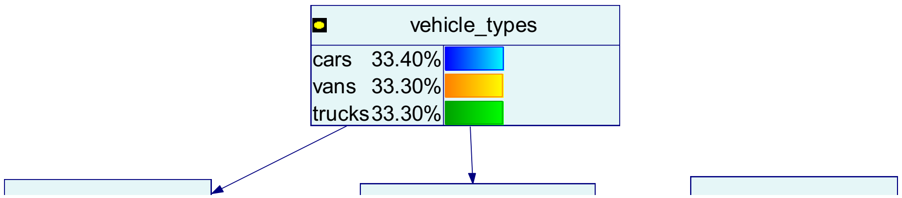
The probability of collision severity may be predicted by the momentum at the moment of the collision. The parameters recognized in this model are :

- Vehicle type distribution
  - fraction of vehicles in tunnel
  - vehicles weight
- Impact: Vehicle speed
- Severity classification by collision momentum = velocity*mass



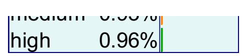
BBN model

Prior data input



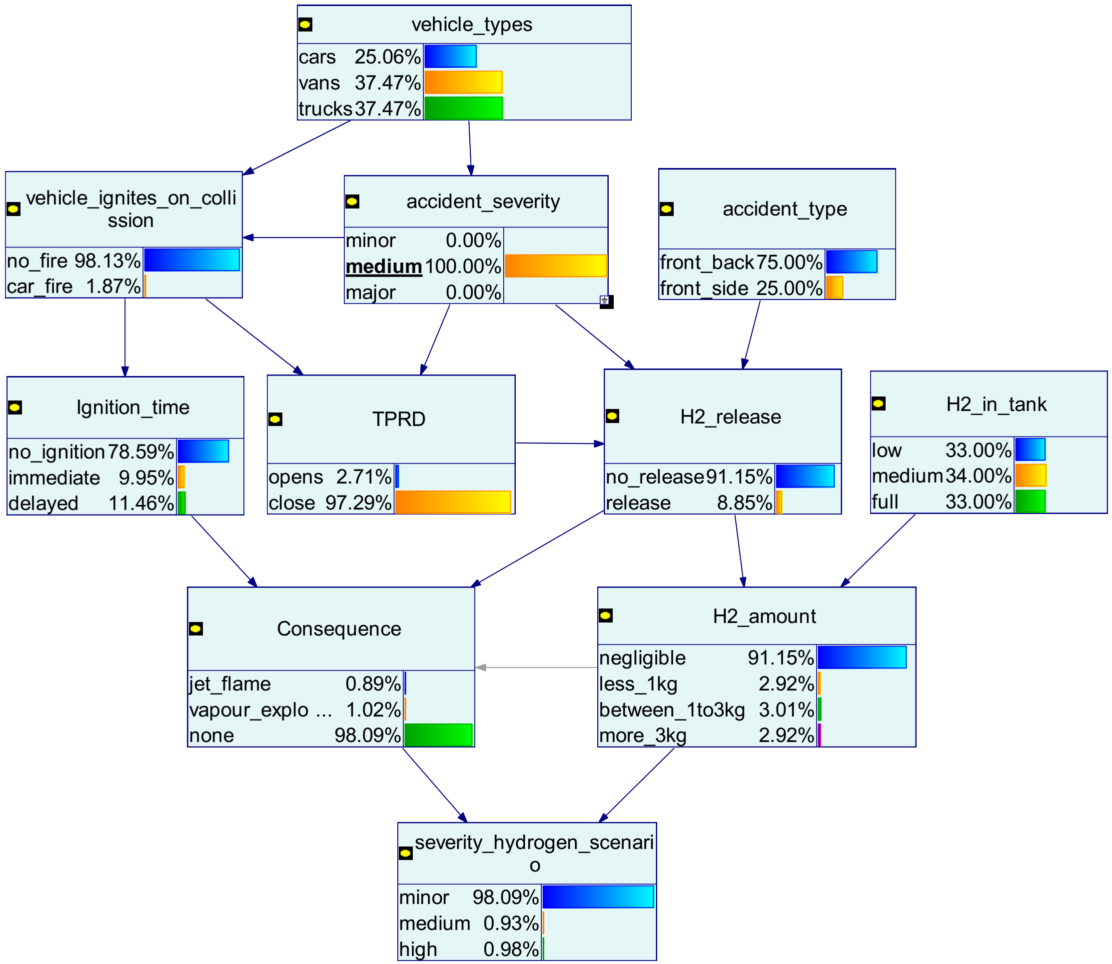
- This example just shows how the BBN works! It does not yet provide a valid quantitative result!!

- Base case
- Data not validated yet!!

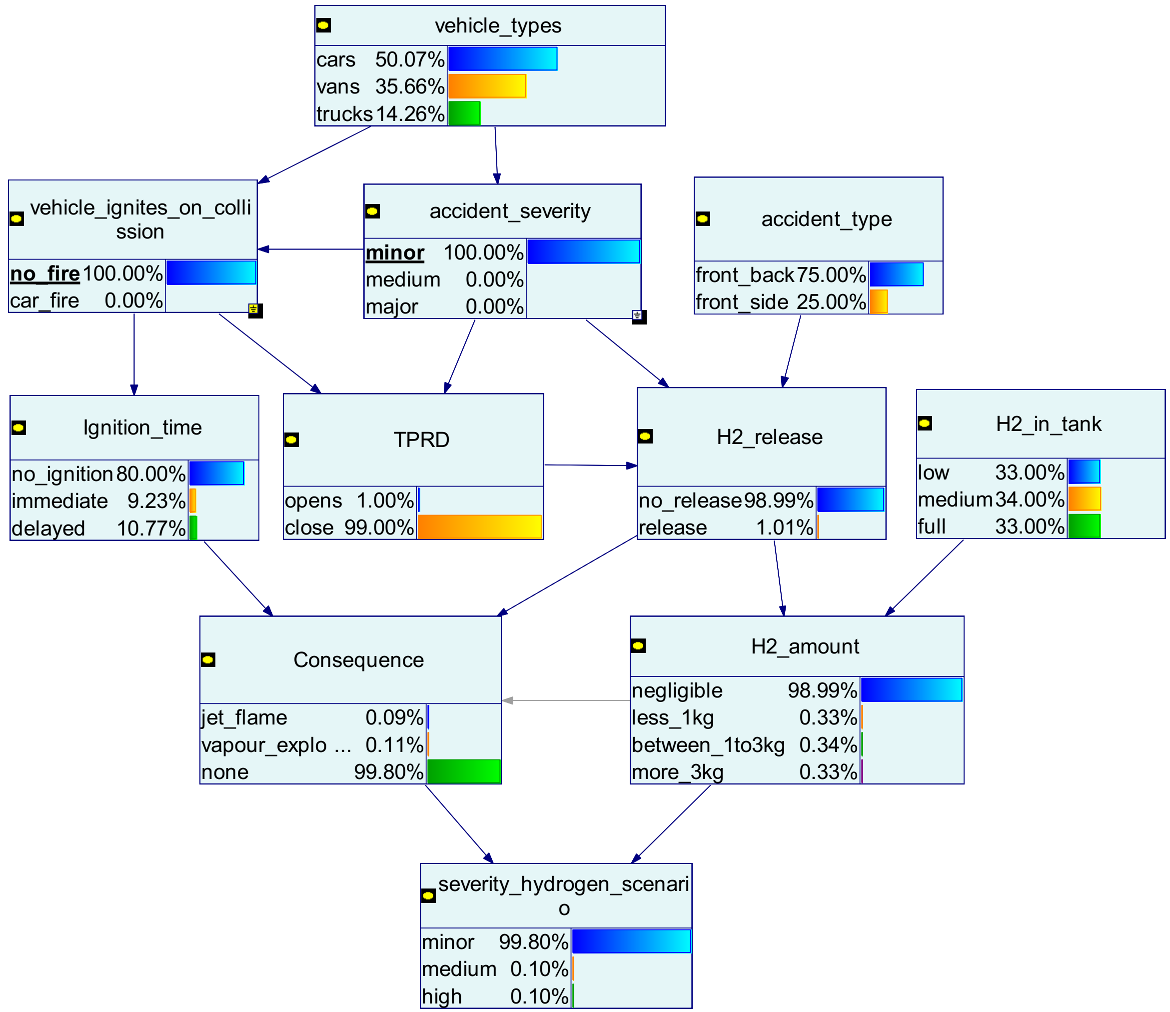


BBN analysis

Instantiating – accident severity

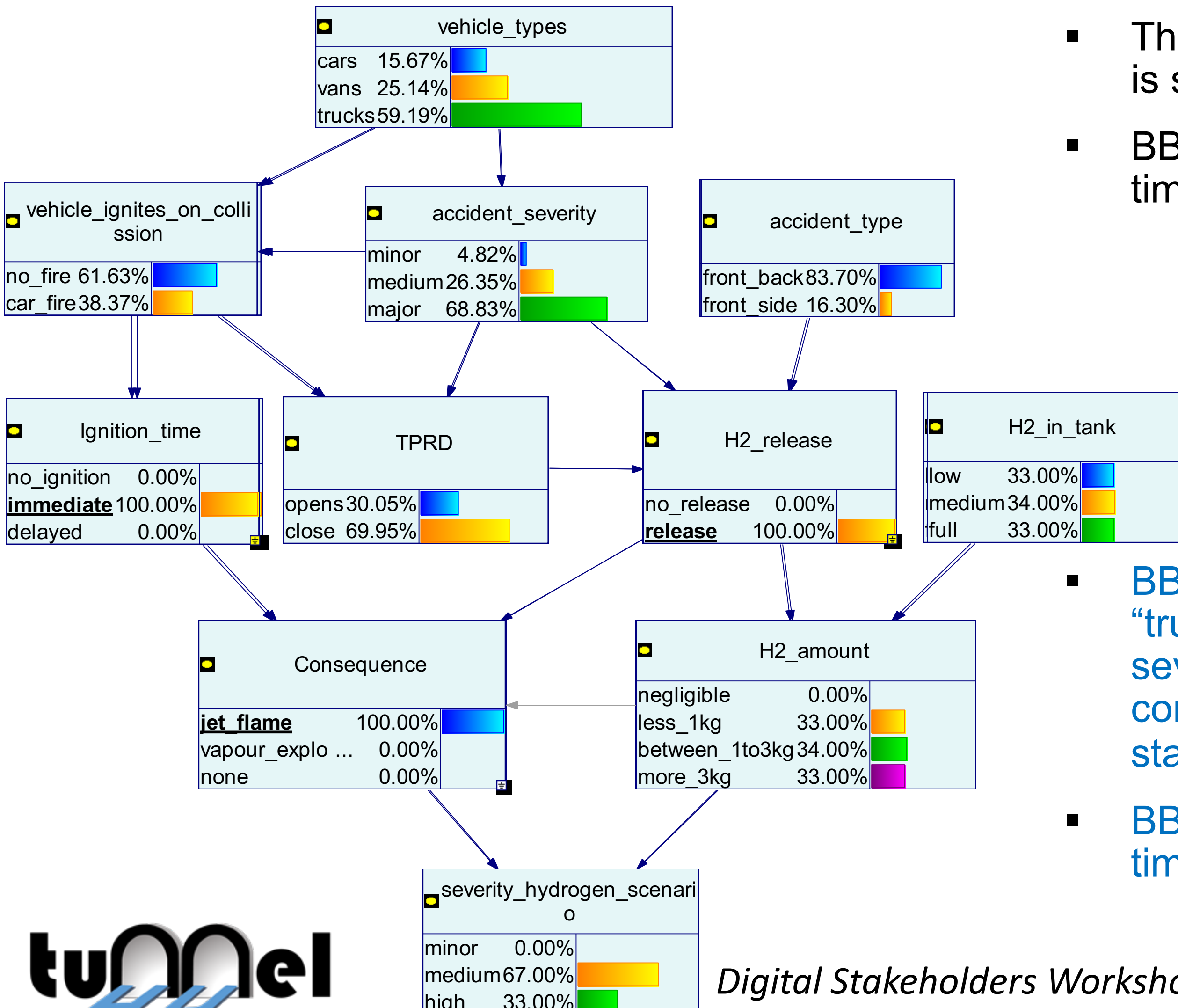


BBN analysis
Instantiating – accident severity



BBN analysis

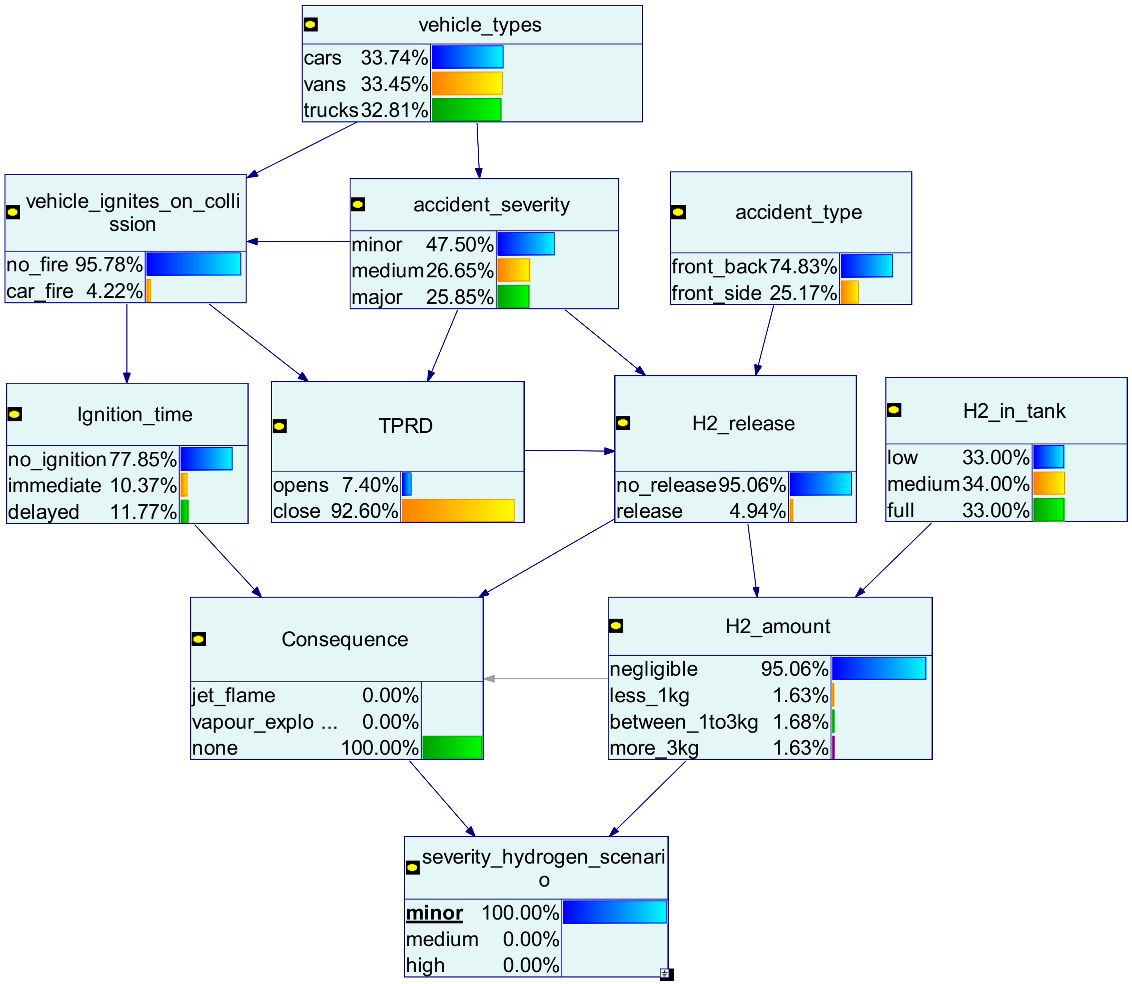
Instantiating -Consequence



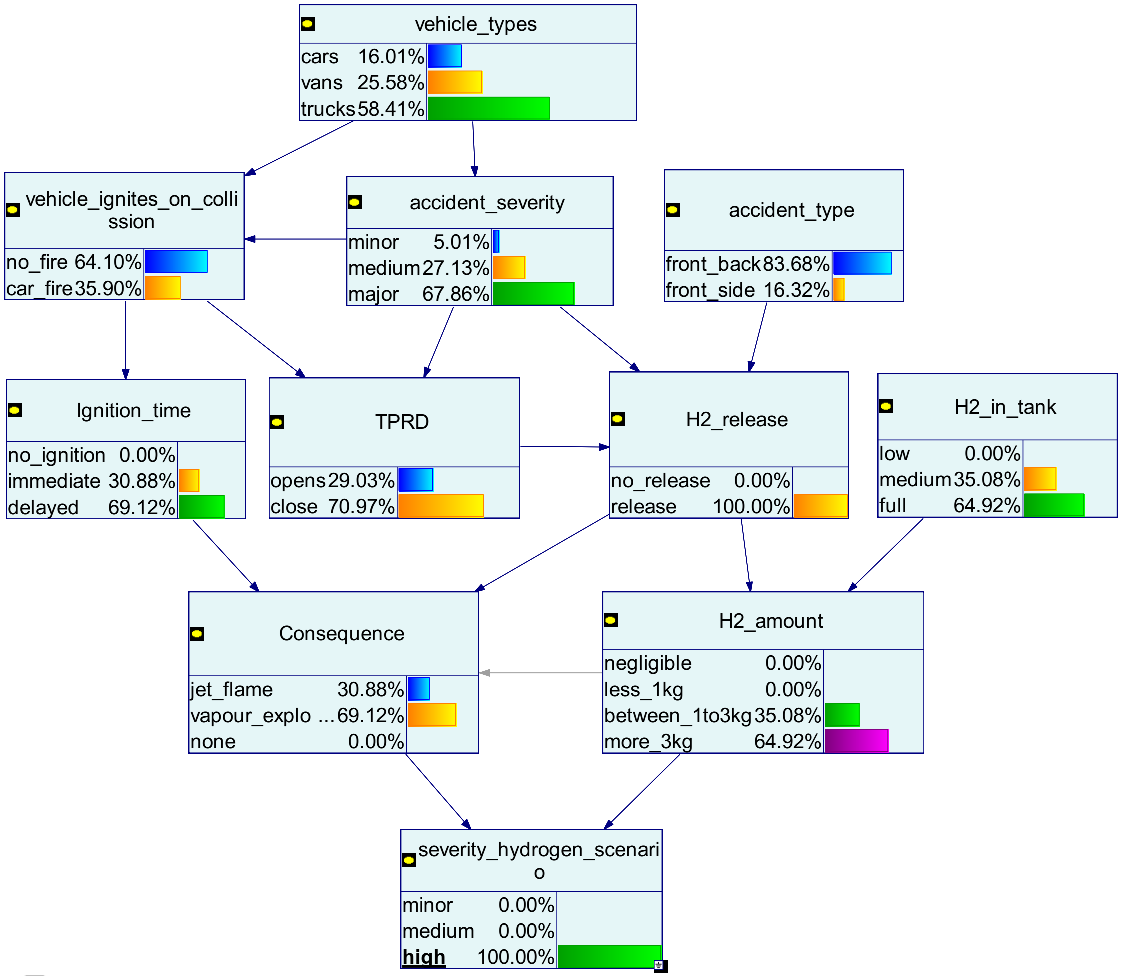
- The consequence state “Jet flame” is set to 100%
- BBN automatically sets the ignition time state “immediate” to 100%
- BBN updates vehicle_types “trucks” to 59% and “accident severity” to “major” 69%→ conditional causes for jet flame state
- BBN automatically sets the ignition time state “immediate” to 100%

BBN analysis

Instantiating – severity H2 scenario



BBN analysis
Instantiating – severity of scenario



Summary
BBN of road tunnel accidents

- A BBN for road tunnel accidents involving hydrogen cars is developed based on assumed data
- Based on traffic data and the severity of collision accidents hydrogen release scenarios can be assessed
- Alternative: the severity of collision may be modelled using hybrid models
  - Opens for application of physical parameters e.g. crash data to predict hydrogen storage damages

Analysis of scenarios:

- BBN model allows updating of the probabilities due to new knowledge for the hole network.
- Instantiating allows valuable sceanrio and cause consequence assessments.

Next steps:

- Implementing real traffic and accident data
- Development of BBN model to include e.g. egress scenarios

Building the BBN
Software used

- GeNIe BayesFusion, LLC; Academic version 2.4.4601.0 - https://www.bayesfusion.com/

Acknowledgements

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