A Real-Time Decision Support System for the Safe and Efficient Routing of Dangerous Goods Vehicles

Vasileios Emmanouilidis,
CERTH/ITI

The problem

- Several thousands of trucks carrying dangerous goods circulate within European roads on daily basis.
- They utilise urban roads, rural roads, highways, tunnels and long bridges and in some case they are not allowed in some of them.
- However the actual accident risk and impact is not calculated.
- In addition, when, due to unforeseen events (traffic jams, accidents, etc.), they need to change route, they do not have any particular guidance on the safest alternative nor are consequences of road choice to the business chain and societal risk calculated.

The proposed solution

- An innovative real-time decision support system (DSS) for optimal routing of Dangerous Goods Vehicles (DGVs), aiming at solving the above stated problems was developed during the GOOD ROUTE research project.
- The DSS is part of an automated system that aims at reducing the overall risk of Dangerous Goods transportation through European roads.
- Several subsystems (telematic modules, on-board units, sensors, real-time data providing modules, etc.) cooperate towards the goal of maximising the safety of such transportation, while also taking into account business demands, network efficiency and conflicts resolution.

The DSS

- It is a software module situated in the Control Centre of the infrastructure.
- It communicates with the other modules of the system through web services.
- It considers every DGV transport request individually.
- For every requested DGV transport, it calculates either the minimum risk, the minimum cost, or the minimum combined-cost route.

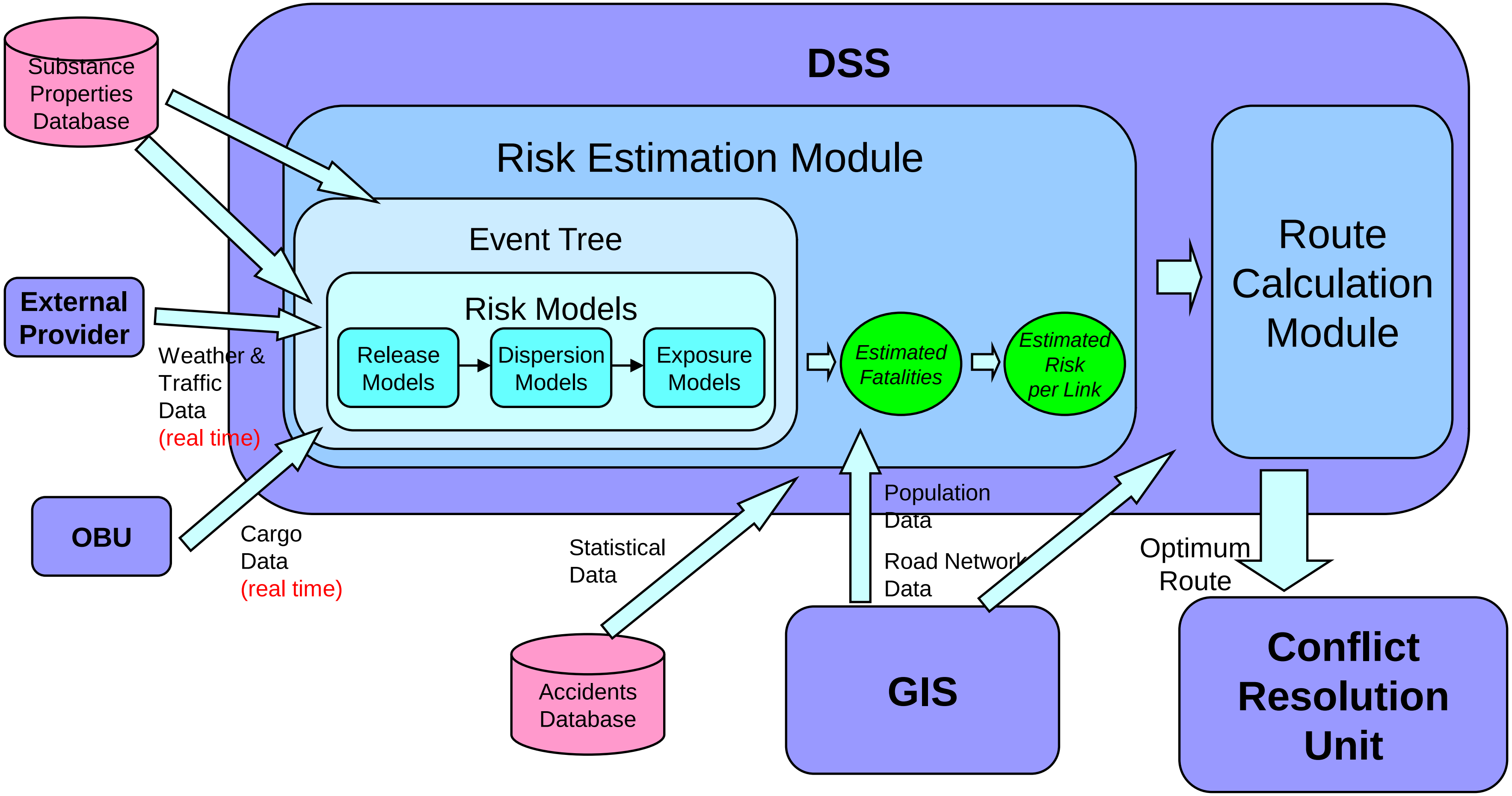
The DSS

- The calculated route is then submitted to the Conflict Resolution Unit, which, having a complete view of the road network, the ongoing and the scheduled routes, or any incidents, accepts it or rejects it.
- In case the proposed route is rejected (e.g. because certain road segments have exceeded their DGV capacity or because of an accident ahead), the DSS will calculate an alternative route, avoiding the problematic parts of the road network.
- The above process continues until the Conflict Resolution Unit finally accepts a proposed route.

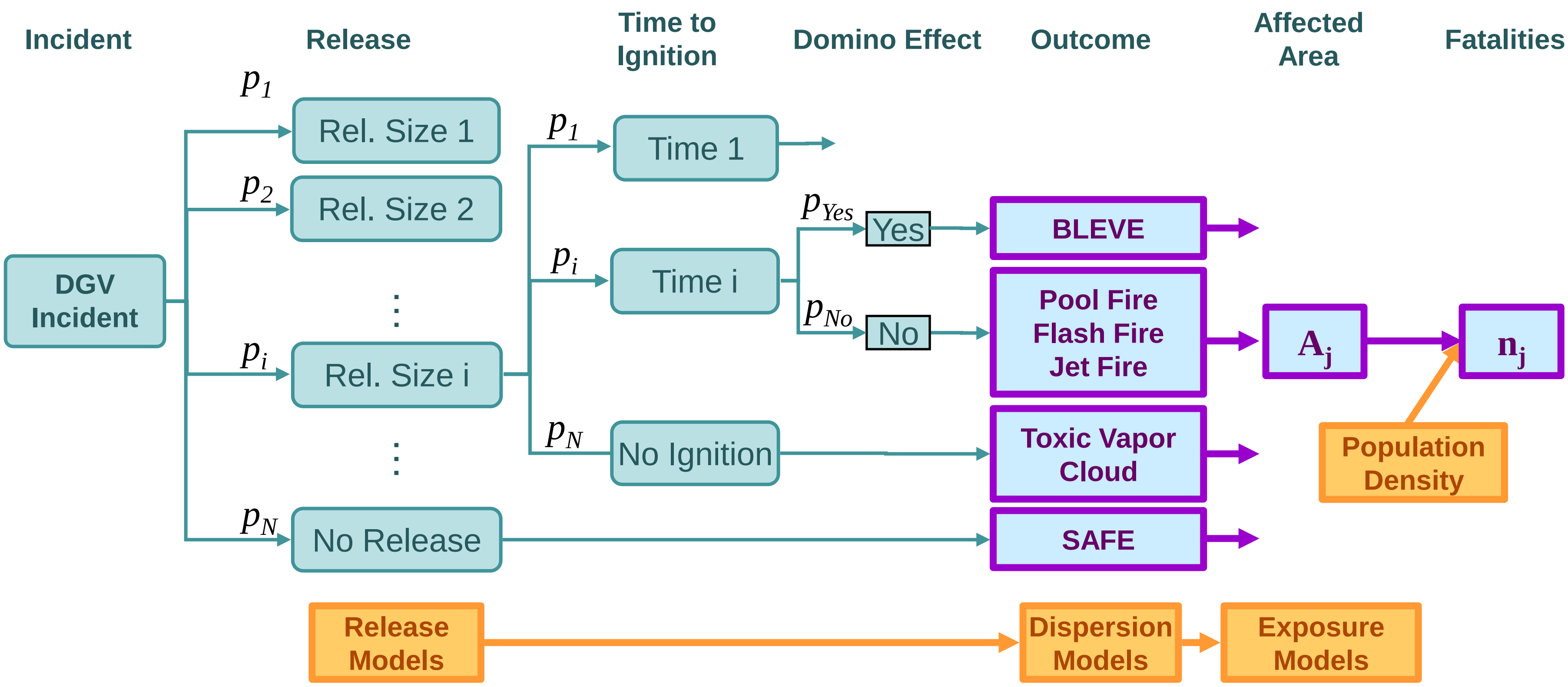
The DSS

- It takes into account the individual and societal risk cost, in addition to the economic cost, and calculates the optimum route by eliminating the combination of them.
- The inputs to the system include
  - the road network,
  - population distribution data,
  - sensitive “hot spots” (e.g. hospitals, schools)
  - real-time as well as statistical traffic and weather data,
  - statistical accident data,
  - road characteristics,
  - real-time vehicle and cargo status
- Those data are, whenever possible, time-dependent, with the day being divided into a certain number of time intervals, each of which corresponds to a different value of the time-dependent data.

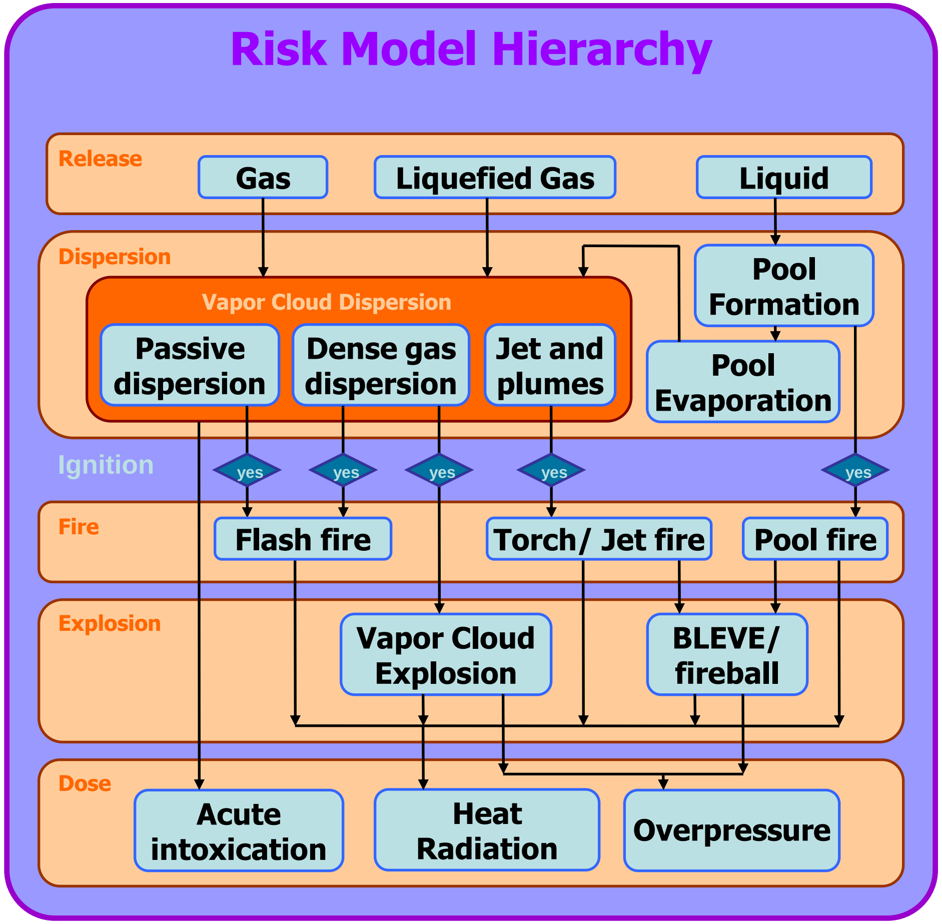
The DSS


DSS
Risk Estimation Module
Event Tree
Risk Models
Release Models
Dispersion Models
Exposure Models
Estimated Fatalities
Estimated Risk per Link
Route Calculation Module
Substance Properties Database
External Provider
Weather & Traffic Data (real time)
OBU
Cargo Data (real time)
Statistical Data
Accidents Database
Population Data
Road Network Data
GIS
Optimum Route
Conflict Resolution Unit

A generalised Event Tree



Risk Model Hierarchy

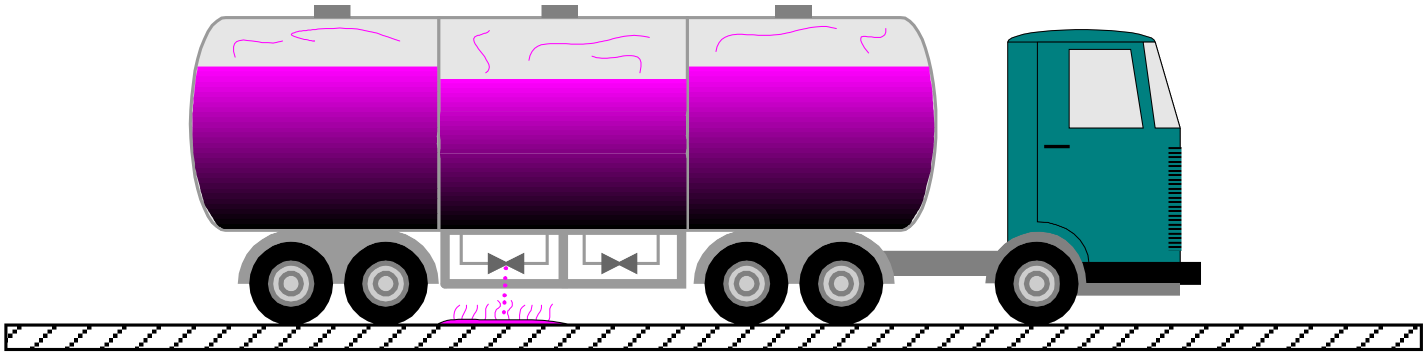


Every logical downward path on the left corresponds to one branch of an event tree…

An example of Events

Liquid Leakage

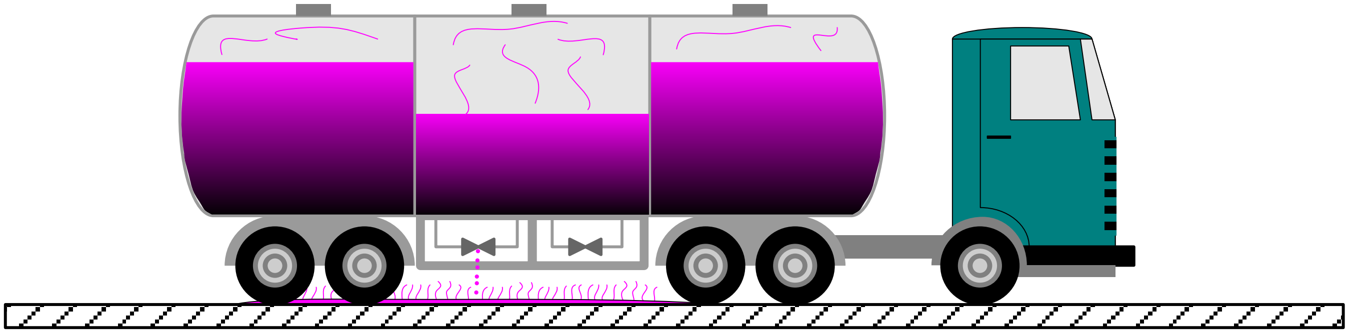
- After an accident or a malfunction a flammable gas leaks. (Associated probabilities for large and small leaks)



An example of Events

Liquid pool formation

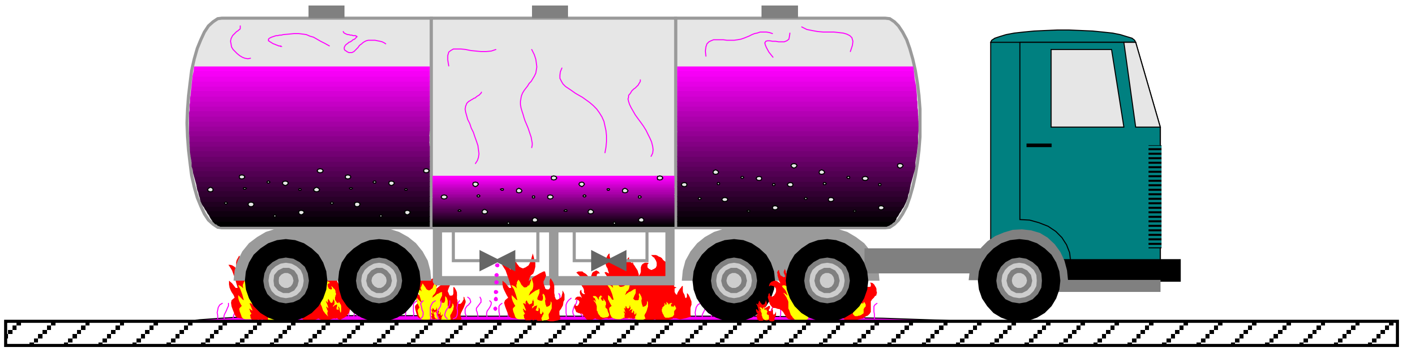
- A liquid pool forms – pool formation model.



An example of Events

Pool fire

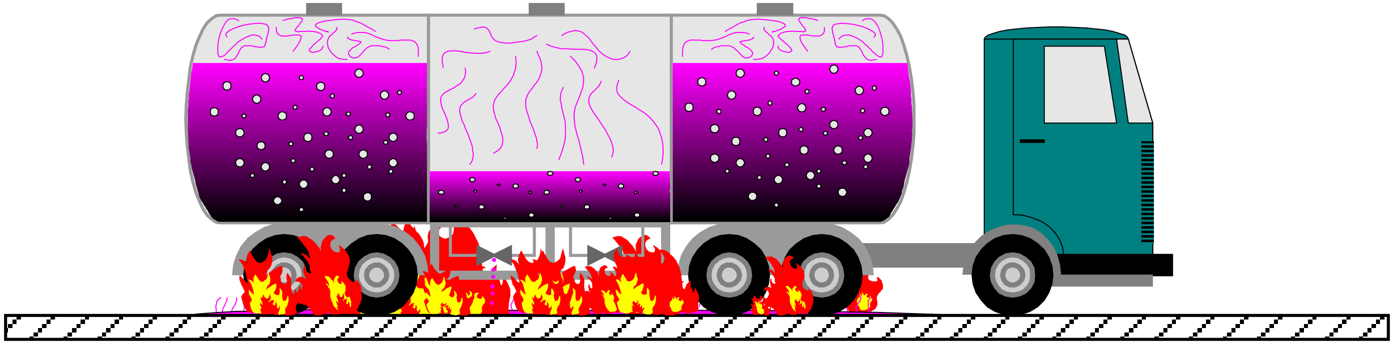
- There is a probability (e.g. 30%) of ignition.



An example of Events

Pool fire

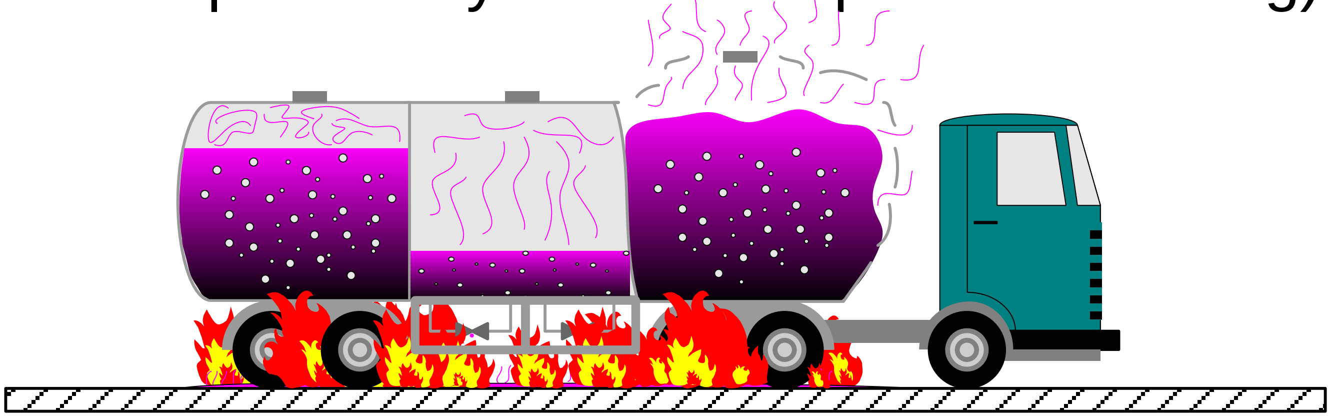
- As the pool fire develops the other compartments are heated and the enclosed liquid may reach its boiling point after a while. (Associated probabilities and models)



An example of Events

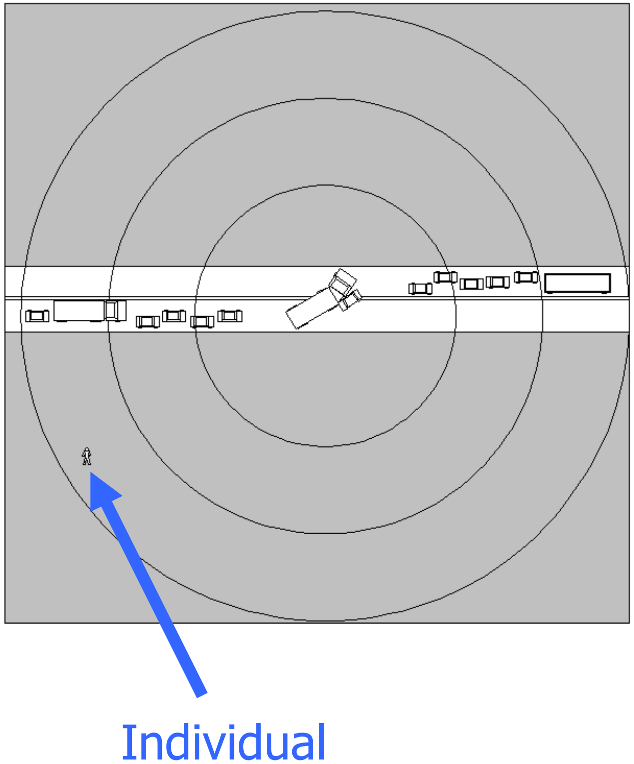
Explosion (BLEVE)

- Pressure builds up while the container walls weaken because of the intense heat. This may result (depending on the amount of leakage and prevailing conditions) in a “boiling liquid expanding vapour explosion” (BLEVE). (Associated probability and consequence modeling)

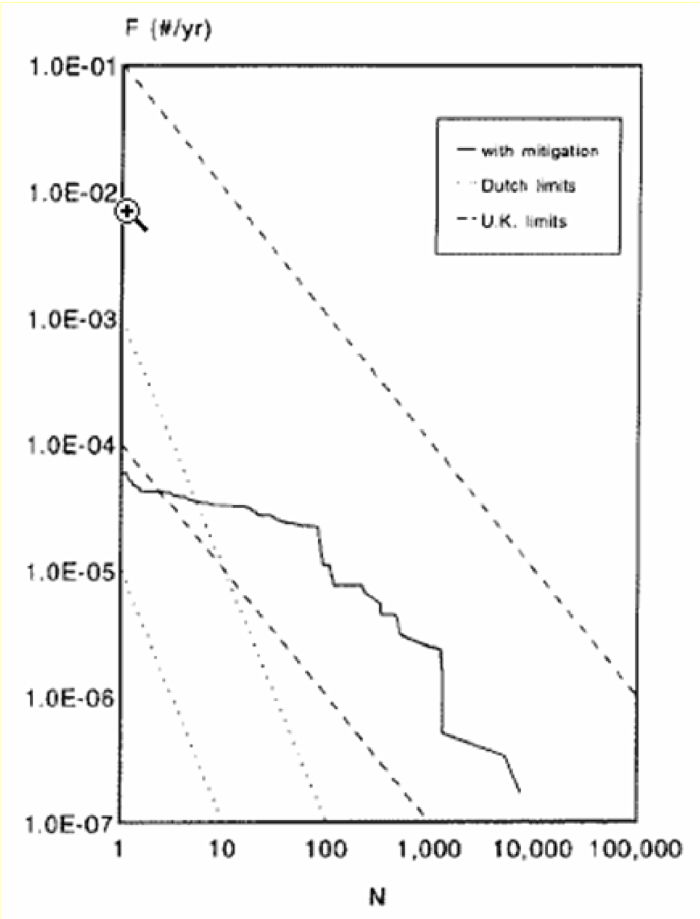


The Individual Risk

- The **Individual Risk** for a point-location around the dangerous goods transportation activity is defined as the probability that an average unprotected person permanently present at that point location, would get killed due to an accident during the dangerous goods transportation activity.
- It is used to estimate the risk of a hypothetical “average” individual as a function of distance from the hazard.



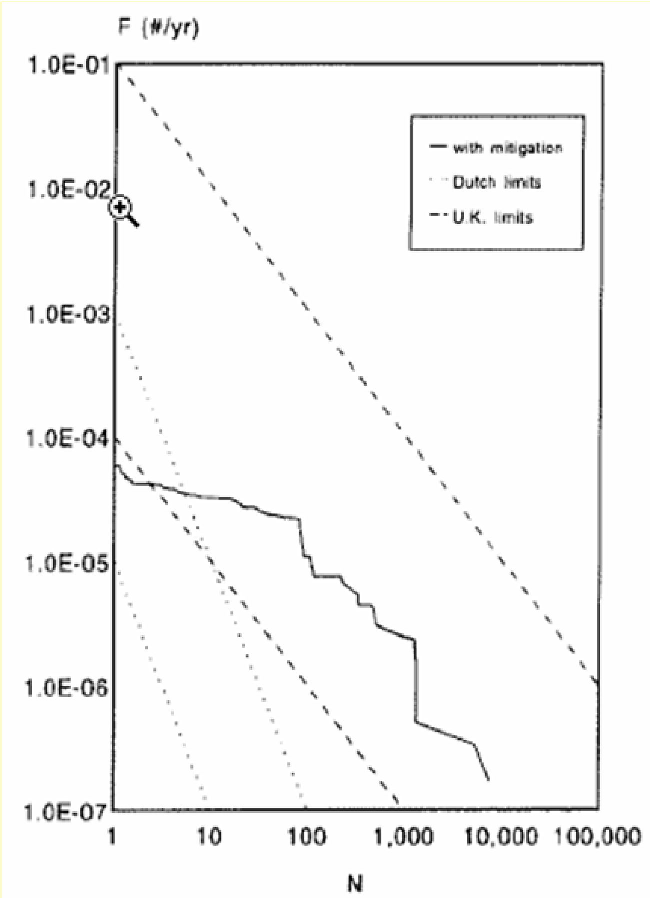
The Societal Risk (F-N curve)



- The Societal Risk is defined as the probability of N or more fatalities due to an accident.
- Societal Risk is usually expressed in the form of cumulative F-N curves, which are plots of the cumulative frequency F(n), of N or more fatalities during a specific time period (e.g. 1 year).
- From an F-N curve a single value C_r can be extracted representing the risk-related cost of a particular road segment, at a certain time interval, for certain weather conditions and for a particular cargo.

$$C_r \propto \sum_n f_n n^a$$

Societal Risk Transformation



α-disutility function

$$\sum_n f_n n^\alpha .$$

Risk Cost

A single value representing the risk of a particular road segment, at a certain time interval, for certain weather conditions and for a particular cargo.

Problems relative to the risk estimation

- **Risk calculations** are complicated and therefore time consuming.
  - They require the numerical solution of complex differential-algebraic systems of ordinary differential equations
- The risk calculation module of the DSS must span the entire event tree for every link of the network for every time slot simulated. Many similar calculations take place.
- Calculations must be performed in real time (order of 10 s).

Mitigation techniques used

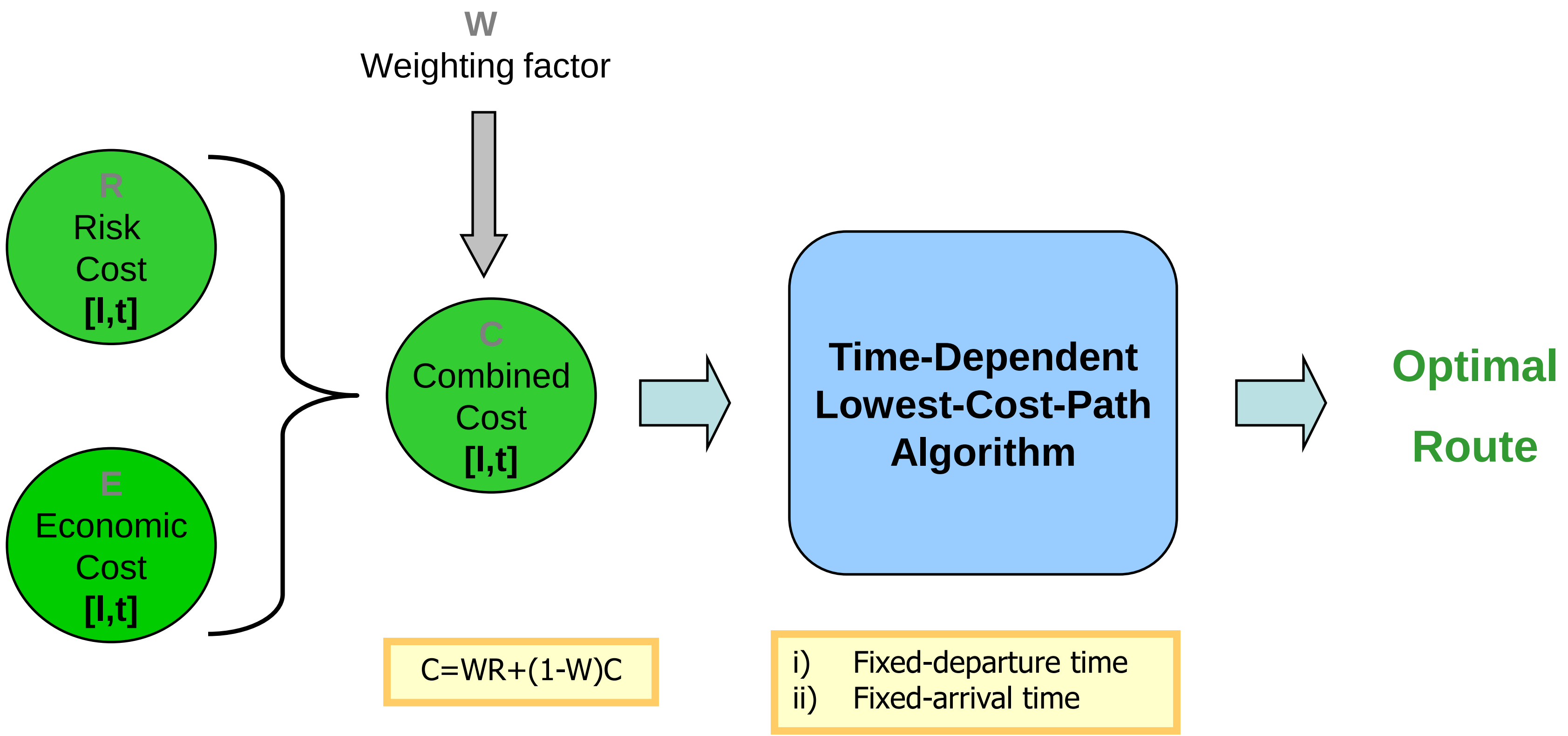
- **Smart caching and interpolation** scheme that takes advantage of similarities in domain of simulation and smoothness of solutions:
  - Caches input variables and results of model runs
  - When new run of a model is required cached results are examined and if the new input parameters are: within the convex hull; and close enough to already existing ones, the new result is calculated by natural neighbor interpolation. Otherwise the model is run normally and new results are added to the cache.

Economic Cost Evaluation

The following parameters are taken into account for the evaluation of the economic cost:

- Average fuel price
- Average fuel consumption
- Work hour consumption
- Tolls price (per vehicle category)
- Vehicle category
- Vehicle average speed

Optimum Route Calculation



l: road segment

t: time interval

Optimum Route Calculation Algorithm

A modified version of the ***Time-Dependent Shortest Path Algorithm for Real-Time Intelligent Vehicle/Highway Systems*** *(Ziliaskopoulos and Mahmassani)* was used.

- The initial algorithm
  - calculates the time dependent paths
    - from all nodes in a network
    - to a given destination node
    - for every time step over a given time horizon
    - in a network with time dependent link costs

Optimum Route Calculation Algorithm

A modified version of the ***Time-Dependent Shortest Path Algorithm for Real-Time Intelligent Vehicle/Highway Systems*** *(Ziliaskopoulos and Mahmassani)* was used.

- The modified algorithm
  - calculates the optimal path instead of the shortest path (minimizing the total combined cost instead of the travel time)
  - can use rest points (points where the vehicle can stop)
  - can also be fixed-arrival time, apart from fixed-destination time

Optimum Route Calculation Algorithm

- Let G=(V,E) be a V node finite directed graph, with E directed links connecting the nodes.
- Every link has a time-dependent cost d(t).
- Let $d_{i,j}(t)$ be the total cost of travelling from node i to node j, when departure time from node i is t.
- Starting from the destination node N and moving backwards, the total cost $d_{i,N}(t)$ of travelling from every node i to the destination node is calculated.
- Let $\lambda_i(t)$ be the total cost of the current shortest path from node i to node N at time t.
- Instead of scanning all the nodes in every iteration, a list of scan eligible nodes is maintained, containing the nodes with some potential to improve the labels $\lambda_i(t)$ of each other node.
- The accuracy of the algorithm raises as the number of time intervals increases.
- The rest points are represented by a cyclic link starting from and ending to the same node.

Optimum Route Calculation Algorithm

- It can handle time-dependent data

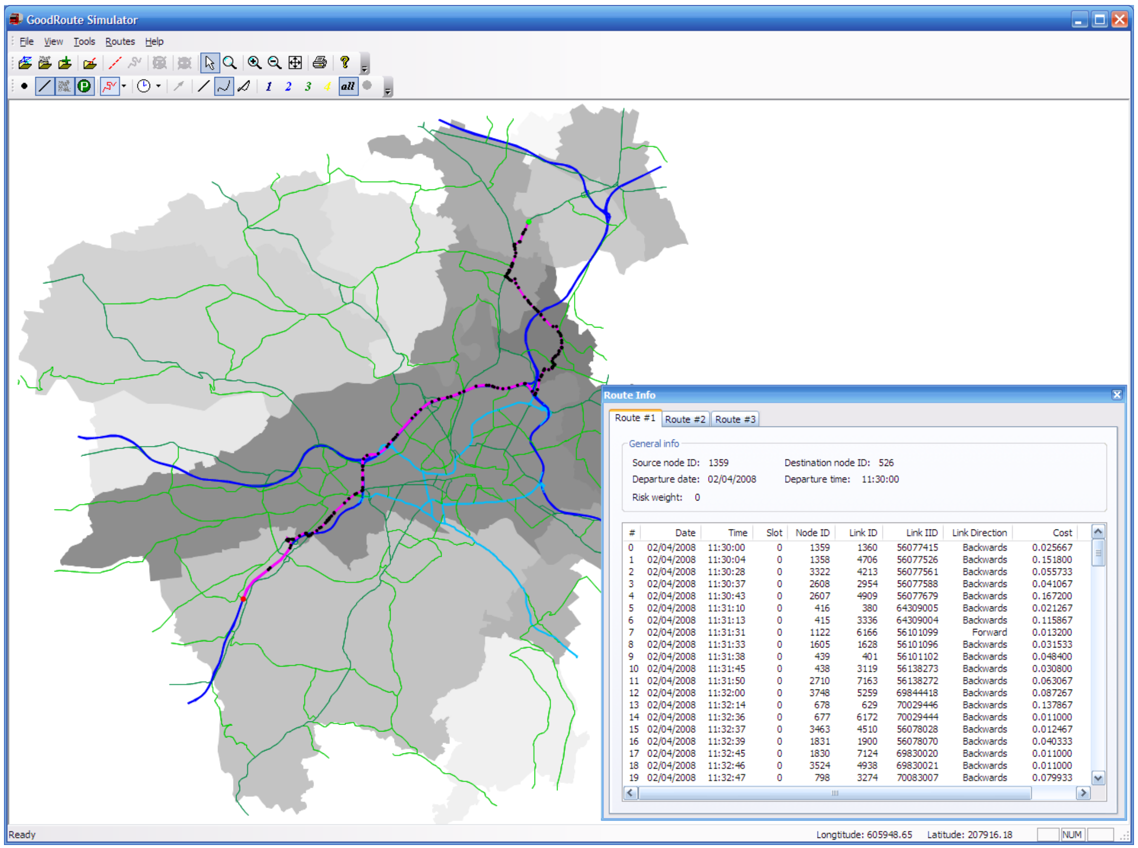
  The day is divided into a number of time intervals, each of them having different values assigned to them. The costs (economic, risk, combined) which are assigned to each road segment form n-size arrays, where n is the number of time intervals.

- It has two versions
  - fixed-departure time
  - fixed-arrival time
- It supports rest (stop) points
- It makes use of parallelization, so as to increase the speed of calculations in multi-core processors, or multi-processor systems

The GOOD ROUTE Simulator

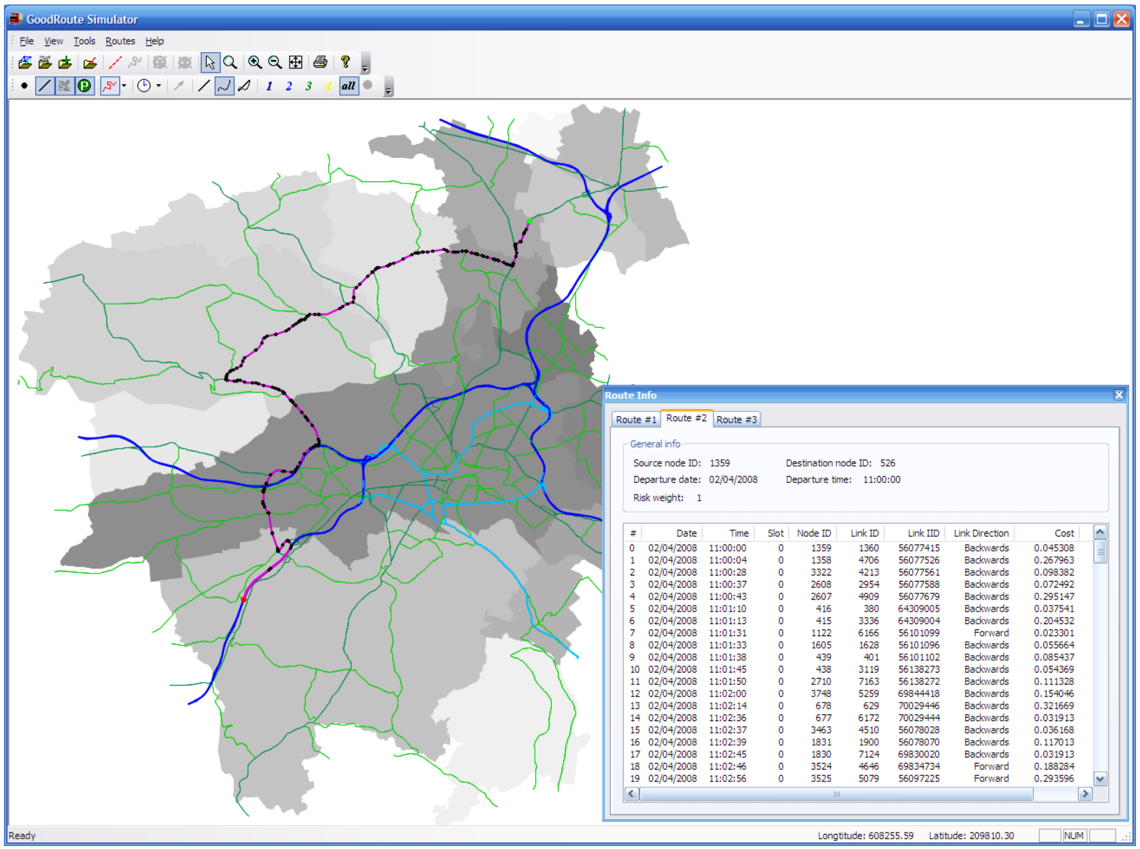
- is a windows application built around the DSS
- simulates the DSS's operation
- is used for visualising and testing the DSS results
- has a functional and effective user-interface
- allows the user to change the economic and risk cost parameters
- allows the user to change the time step that is used by the route calculation algorithms
- displays the road network and the population distribution for every part of the day (time interval)
- offers many options regarding the display of the GIS data
- gives the user plenty of information for the nodes, links (road segments) and routes, just with a click of the mouse

The GOOD ROUTE Simulator



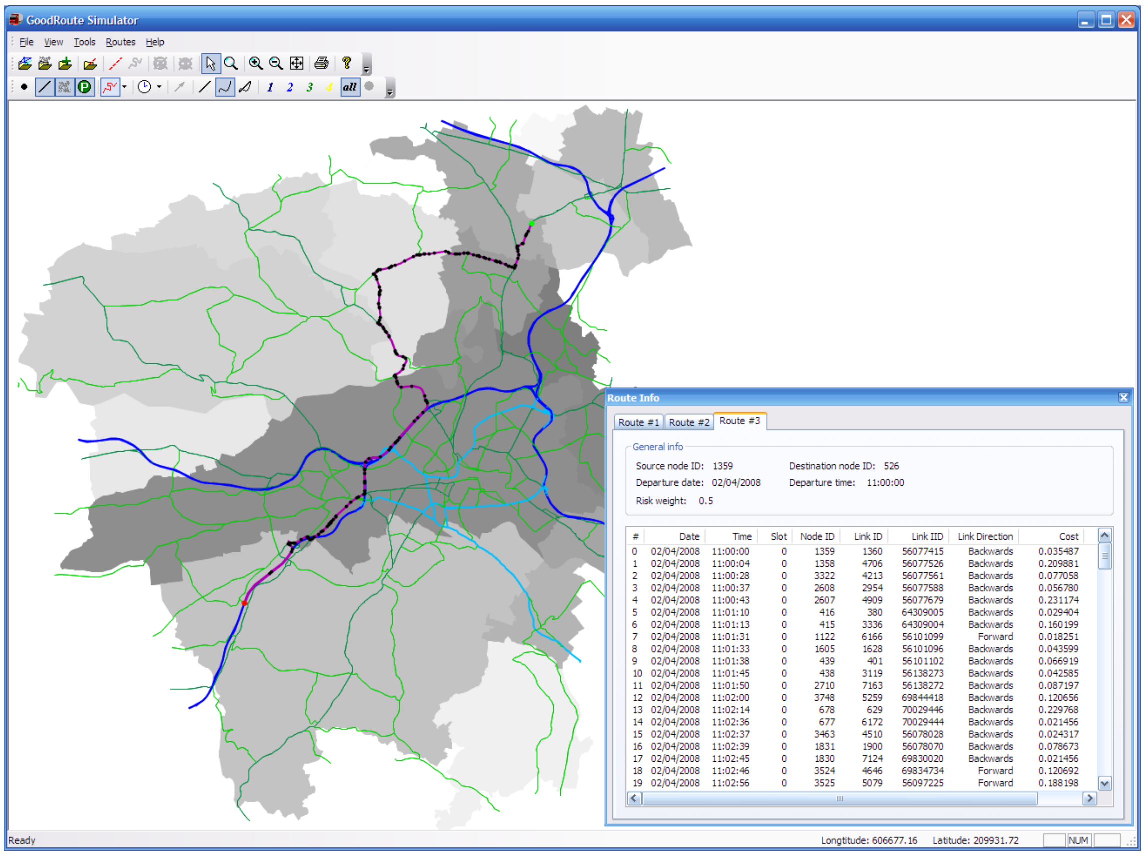
The **minimum economic cost route** between two locations.

The GOOD ROUTE Simulator



The **minimum risk route** between two locations.

The GOOD ROUTE Simulator



The **minimum combined cost route** between two locations (w=0.7).

Possible extensions

The described system can be extended to also calculate and eliminate:

- the long-term damages to people's health (e.g. as a result of a chemical intoxication that doesn't produce instant measurable damages)
- the damage to the environment
- the damage to the infrastructure

Thank you for your attention!