A prototype of a computerized accident risk assessment tool for freight transport in Finland has been constructed based on a concept developed in an earlier stage of the study project. The tool is based on a realistic description on the road, rail and waterway networks, and real data on traffic flows and the occurrence of injury accidents on freight transports in Finland. The estimates of accident risk are based on Bayesian models and take into account both accident frequency and severity of consequences. The output from the tool includes the probability of an injury accident and the expected numbers of persons injured or killed within a journey or journeys required to deliver a given amount of cargo from one place to another by the transport means and route as specified by the user. An interactive graphic user interface with map applications is provided to support routing and planning of the transports in the network models. The prototype tool is applicable to freight transport by road, rail, or water, as well as to multimodal transports combining these. The risk of accidents in transshipments and other handling of goods within a specific transport assignment are also considered.

The main motivation for the risk assessment approach and the associated prototype tool development has been to supplement the traditional, accident statistics based reactive views of traffic and transport safety with a quantitative risk based proactive approach considered more suitable for the needs of freight transport planning and management, both strategic and operational. The development work has been funded by the Ministry of Transport and Communications of Finland and VTT.

1. INTRODUCTION

As any modern society, Finland relies heavily on efficient logistic systems. Related to this, freight transport volumes are continuously increasing. This implies to export and import of goods by sea, as well as to inland freight transport by road and rail. While performing this function and meeting the associated economic and other needs, freight transport is also concerned in accidents, killing every year tens of people, injuring hundreds and causing extensive material damage. Majority of such accidents take place on roads.
On average, about 100 people get killed and around 800 injured yearly in Finland on road accidents involving trucks and lorries. The number of deaths accounts for approximately one quarter of the total yearly number of deaths experienced in road traffic in Finland in the recent past years. Reaching the government adopted vision for improved traffic safety, and reducing the overall number of yearly road traffic deaths to less than 250 by the year 2010, obviously require safety improvements also in relation to freight transport.

The head-on collision accident between a full trailer and a tourist bus at Konginkangas in Central Finland on March 2004 made everyone, including the general public and the media, very conscious and concerned of the accident risks associated with freight transport on the Finnish roads. The tragedy resulted in the death of 23 young people and severely injured thirteen of the bus passengers. By the consequences it is the worst accident that has ever happened on the Finnish roads.

Alongside with the thorough official investigation of the tragedy, the accident triggered discussions at various forums on freight transport safety, questioning, for example:

- the design and condition of the current road network,
- the rationality of transport mode selections,
- the role of safety in transport planning and management in companies,
- the role of safety in purchase decisions on transport services,
- the responsibilities within the transport chains in ensuring safe transports,
- safety culture in the professional transport sector.

Different types of improvements in the road network, selection of safer modes and routes for the transports, better planning and management of transports with accountability for safety, and a stronger safety culture were brought up as some prospective measures to facilitate safer freight transportation.

Development of a computer-based accident risk assessment tool was seen useful in this context especially to facilitate freight transport planning and strategic decision making. An easy-to-use quantitative tool covering the different freight transport modes could provide means needed for comparing decision alternatives with respect to their expected safety performance. These could be alternatives at various levels of the transport system considering for example upgrading of road sections, placement of industrial activities or logistic terminals, routing of particular transports, etc.
2. CONCEPT FOR ACCIDENT RISK ASSESSMENT

2.1 Overall concept

The probabilistic approach described in this paper has been developed to support the assessment of accident risks and safety in freight transport. The risk assessment approach indicates the likelihood of accidents and the risk of severe injuries and deaths as foreseen in relation to a given freight transport assignment. Different to many previous works, especially to those dealing with transport of dangerous goods, the focus of the assessment has been limited to the risk of casualties among people directly involved in the predicted accidents, in other words, the transport workers and the other road and fairway users.

The specified approach is applicable to freight transport by road, rail or water, as well as to multimodal transport combining these. In addition to traffic accidents, the risk of accidents in the transshipments and other handling of goods within a specific transport assignment are also considered.

A general framework or concept for freight transport accident risk assessment established to support the development of the accident risk assessment tool is shown in Figure 1. The overall concept illustrates the main modules that are seen to be needed in such tool. The adopted modular structure supports step-wise refinements of the approach.
The risk assessment concept is built on geographic network models that define the existing routes available for freight transports by road, rail and water. In the models the routes are broken down and defined in the form of (interrelated) distinct links along which any given transport assignment can be routed from its geographic origin point to its destination point in the way desired. By linking the history records of actual traffic volumes and experienced accidents with the defined links, distinct risk parameter values can be estimated and associated with each individual link. The risk parameter values (of a link) characterize the accident risk which a transport becomes exposed to as it travels through a particular link.

When performing a risk assessment, a given transport assignment is divided into specific transport operations by specific modes and corresponding routes. For each specified operation, the risk of accidents and casualties is then estimated by considering a single realization of the transport as envisioned for this particular operation. The assessment is performed link by link over the defined transport route. Depending on the mode of transport in question, different sets of conditions affecting the risk of accidents on the network links may be accounted for in this assessment. The risks of accidents in the freight terminal activities relevant for the considered transport case are estimated also. Finally, the risk results calculated on individual route links are aggregated over the transport modes and the corresponding routes, also taking into account the number of separate transport executions found necessary in each transport mode to carry out the considered transport assignment.

2.2 Risk modelling

Bayesian estimation of accident rates

The number of accidents taking place in road traffic is typically modelled as a Poisson process. Then the number of accidents at some road link \( i \), as a function of exposure \( s \), i.e., \( N_i(s) = y_i \), follows the Poisson distribution with parameter \( (\lambda_i s) \). The expected value for the number of accidents corresponding to particular exposure \( s \) is then \( E[z_i] = \lambda_i s \). Parameter \( \lambda_i \) is called accident rate, and describes the relation between the number of accidents and the amount of exposure. Parameter \( \lambda_i \) is dependent on several factors related e.g. to vehicles, drivers and the road environment. Basically, parameter \( \lambda_i \) is unknown and can be determined accurately only when the observation period approaches infinity, and under invariant conditions.

The estimation of accident rate \( \lambda_i \) can be conducted using several statistical approaches, e.g. method of moments, maximum likelihood, or Bayesian estimation. Bayesian modelling has been adopted here to estimate the accident rates for the road links. The main reason for selecting the Bayesian approach is that while one wants to estimate the accident rate for each individual link, the encountered injury accidents are rather sparse. Thus, for many links, no accidents would be observed - not even during longer periods of time.
In Bayesian modelling, the considered parameter, in this case the accident rate \( \lambda_i \), is not given an exact numerical estimate, but the prevailing conception of the parameter value is described by a probability distribution. The basic idea of the Bayesian estimation of accident rates applied for the road links is the following: First, roads have been classified into a set of road categories based on selected risk related characteristics. For each link belonging to a particular road category, the accident rate is then estimated based on the accident and exposure data (exposure in terms of vehicle kilometres) accumulated for the road category over the specified time window. This gives the prior distribution. Next, this prior estimate is conditioned by the accident and exposure data specific to the link. This gives the posterior distribution. The expected value of the posterior distribution is applied as the accident rate point estimate for the link, and is used in calculating the risk figures for the transport cases.

The mathematical details of the applied simple Bayesian modelling approach are out of scope of this paper. Information on the details can be requested from the authors (first name.last name@vtt.fi).

**Consequence severity estimation**

Consequence severity of accidents is typically measured by the number of people getting killed or injured in the accidents.

The number of people killed or injured in an accident \( n_q \) is a random variable. Based on accident statistic data, discrete distributions \( p(n_q) \) can be estimated to describe the death-toll and the number of people injured in the accidents. The expected value of the severity distribution can then be used in the risk calculations as the point value to describe the expected consequences. On the other hand, the distributions also allow estimates to be produced on the probability or expected number of accidents with a certain severity value or threshold.

At least for the prototype, Poisson –distribution that is defined by a single parameter was considered a simple suitable model for describing the consequence severity in freight transport and freight vehicle related accidents.
3. PROTOTYPE TOOL

As the first step of the tool development process, a tool prototype was constructed to demonstrate the feasibility of the proposed accident risk assessment concept and to support the elicitation of specific user requirements regarding the final tool. The prototype was designed to introduce the main functionality needed for the assessments while certain simplifications were adopted in the user interface implementation.

3.1 System architecture and software tools

The system architecture to implement the accident risk assessment concept is outlined in Figure 2. It consists of the actual risk assessment tool and the means provided to keep the specific tool modules, i.e. the network models and the risk data, updated with respect to changes in the real operating environment. In practice, the tool modules could be updated once a year when new data records on occurred accidents, traffic flows and network developments are released for the previous year. The contents of the different tool modules are described in more detail in the following chapters.

The risk assessment prototype tool has been implemented using the following open source –tools and certain software modules provided in the tools:

- Thuban software tool to support the interactive map applications (http://thuban.intevation.org/),
- PostgreSQL database software tool to handle the network models and the risk data (http://www.postgresql.org/),
- Python programming tool to implement the risk calculations (http://www.python.org/),
- a software module implementing the routing algorithm by Dijkstra (http://cartoweb.org/cwiki/PgdijkstraWin32).

The prototype tool also provides the tool user the means to save the data of the assessed transport case into a file for later retrieval and use. The case file saves only the necessary parameter values on the transport case and the selected route that will allow repeating the risk calculations for the case.

Furthermore, the prototype tool allows the user to easily export the risk calculation result tables to other applications, e.g. MSExcel, for further processing or reporting.

The prototype tool has been implemented as a desk-top version, but could as well be transferred to a web –based system in the future.
3.2 Network models

The main road, railroad and waterway networks servicing the freight transports in Finland have been implemented in the prototype tool. In addition, a terminal network including ports and freight railway stations has been specified for considering the handling of goods between the transport modes used.

The currently implemented road network model covers the public main roads in Finland. It consists of 11,900 links with the total length of about 13,000 kilometres. Thirty-two different road categories based on road type, area type (rural vs. urban), road width and speed limit have been identified and applied in defining the road links. The road network implemented in the prototype is based on data on the geographic location and characteristics of the roads provided in the public road database ("Road register") of the Finnish Road Administration. The road network implemented in the prototype represents the actual main road network as available in year 2004.
The currently implemented railroad network model consists of the state-owned national railroad network as defined in the Network Statement by the Finnish Rail Administration. The rail network implemented in the prototype tool has a total length of about 6,000 km. The implemented rail network excludes the private railroad sections (about 1,000 km) connecting large industrial sites or freight ports to the national network. The different types of rail lines in use in the actual rail network have not been separated in the prototype.

The currently implemented waterway network model includes the waterways to the main seaside freight ports in Finland and the main routes to the southern Baltic Sea. The coastal fairway links and the open sea links have been separated in the prototype. The coastal fairway links have been specified according to the issued nautical charts while the open sea links mimic the routes that the freight ships most typically use. The traffic separations specified for the east-bound and west-bound traffic in the Gulf of Finland have also been taken into account.

The freight terminal network model implemented in the prototype covers the main freight ports on the Finnish seaside (total of 20 ports) and a set of freight railway stations (total of 33 stations) available for transhipment of goods between transport modes or within a mode. In addition, each node in the road network model is considered as a potential freight terminal node where loading or unloading of the transported goods can take place. At present, the freight terminal nodes are provided mainly to help the tool user to specify certain nodes (e.g. a particular port or a rail station) through which he/she want the transport case to proceed, i.e. to be routed.

### 3.3 Risk data

The risk data needed for the risk calculations in the prototype tool is provided in the form of specific risk parameter values. These risk parameter values are calculated beforehand for each network link (and terminal node) in all condition combinations feasible for the link (or the node), and recorded in the tool database for retrieval. The risk parameters specified for the network links (and terminal nodes) include: 1) the accident rate estimate, 2) the Poisson-distribution parameter estimate for the death-toll, and 3) the Poisson-distribution parameter estimate for the number of persons injured in case of injury accident occurring.

**Road links**

The history data on injury accidents and the corresponding traffic flows on freight transport are utilised to produce the risk data for the tool. Regarding the main road network, the risk data modelling to produce the risk data for the road links was performed using the following sources of data.
The national data records on police reported injury accidents on the Finnish road network were imported and used to calculate the accident rate estimates for the road network links in the prototype tool. The case data applied in the calculations included those accident cases reported on the public main roads in which at least one of the parties involved had been a truck or lorry. In the five year period between 1999 and 2003, 1,251 case records in total were identified fulfilling the given search criteria. However, in about 10 percent of cases the incident could not be linked to a particular link of the road network model, and because of this could not be used in the accident rate calculations.

The traffic flow rate information available in the Road Database of the Finnish Road Administration was adopted to use in estimating the vehicle-kilometres performed by truck and lorries on the road network links. The traffic flow rate information in the Road Database describes the daily average number of vehicles observed as going through a particular road section. Separate figures are provided for heavy traffic and the overall traffic. The information is based on traffic counting studies performed for the road sections. The information is mostly based on automatic traffic measurements on the road network. At the end of year 2003, about 250 automatic traffic measurement points were in use on the public main roads.

The traffic flow rate information of year 2003 was used in the prototype as the starting point in estimating the heavy-vehicle traffic flows over the five year time period between 1999 and 2003. To reduce the work, the traffic flows of the four previous years corresponding to the accident data used in the accident rate calculations were simply determined by assuming a constant percentage value to modify the estimate. The percentage value was selected to reflect the average yearly increase of heavy traffic observed over the past years. For simplicity, the same percentage value was assumed to all roads and links across the whole road network model.

To consider variations in the road accident rates due to time of year, day of week, and time of day, specific coefficient values were determined for adjusting the traffic flow information to the different condition alternatives when calculating the accident rate estimates. The coefficients for season, weekday and hour adopted for the prototype were based on published previous studies by the Finnish Road Administration, and were specified regionally for nine Road regions covering the road network model implemented in the prototype. Coefficients to adjust the initial accident rates to certain road surface conditions were also determined. These coefficients were estimated for the prototype by using expert judgement supported by the findings of some studies looking at the effects road conditions may have on accident occurrence. Identical road condition coefficients were used in the prototype for all road categories across the country independent on the timing of the road use.
The parameter estimates to describe the expected severity of consequences for the injury accidents taking place on the road network links were determined based on the same accident case data retrieved for the accident rate calculations. Poisson-distribution was presumed sufficient in this case to describe the death-toll and the number of persons to be injured in the accidents. The type of the lorry involved (i.e. lorry with or without a trailer) and the speed limit of the road link were found as two main factors affecting the severity of consequences. Separate severity distributions were thus determined for the two vehicle types considering three different speed limit categories. The Poisson-distributions produced for predicting the death-toll turned out to fit well to the accident case data. A less perfect fit was found regarding the injury outcomes. This was expected since the accident case data used as the basis for the parameter estimation is strongly filtered regarding accidents with no people injured.

**Railroad and waterway links**

Because of deficiencies of data readily available on accidents or the corresponding traffic flows, the risk parameter values could not be specified in the same level of detail for the railroad and the waterway networks. In case of the railroad and waterway links the prototype consistently applies generic risk parameter values produced for a particular link type (i.e. rail, coastal, or open sea). The risk parameter values in the prototype determined for the rail and sea links are generic also with respect to transport conditions and the transport means or equipment used.

**Terminal nodes and material handling activities**

Lack of readily available history data to support production of more specific risk parameter estimates forced to initially accept coarse generic estimates also for the loading, unloading and other goods handling activities taking place in relation to road and rail transports. In the prototype, generic initial accident rates have been specified for these activities in terms of accidents per ton of goods handled.

The accident rate calculations performed based on statistical data available in national databases on occupational accidents and the cargo volumes passed through the Finnish ports suggested rather similar injury accident rates for all freight ports. The port handling only crude oil and oil products transported by tankers was found to have a lower accident rate, and to be the only exception.

**3.4 Calculation routines**

The main calculation routines implemented in the prototype consider the routing of the specified transport assignment and the calculation of the risk figures for the case.
For **routing**, the prototype tool applies the network models and the routing algorithm by Dijkstra to find, considering the user specified origin, destination and possible intermediate nodes for the transport to pass, the route that minimizes the user selected cost function. The minimum route is determined for the overall travel. The length of the route and the expected time duration of the transit are the two alternative cost functions currently provided for the user to select. The routing algorithm has been implemented in the proto by using a particular open source software module.

The routing routine specifies the route for the transport case in the form of an ordered set of network links. This ordered set of links establishes the basis and structure for the accident risk calculations.

**Risk calculations** utilise the accident rate and consequence severity estimates determined and assigned for the network links beforehand as described in Ch. 3.3. The risk calculation routine first calculates, *link by link*, the probability of experiencing an injury accident on that particular link, and the number of persons expected to be injured or killed on the link on such accident. These risk figures are calculated by considering a single manifestation of the transport in question when passing through the link. The risk figures are calculated taking into account the particular conditions that the user may have specified for the link or the corresponding route section. In addition, reference risk figures are calculated by considering the same transport taking place on the link in unspecified, general conditions. In the present prototype, the consideration of different transport conditions however is only available in relation to road transport. In road transport, variations in accident risk according to time of year, day of week, time of day, road surface conditions, and the vehicle type used can be considered.

The **risk figures for the overall transport assignment** are produced by aggregating the risk figures calculated for the individual links over the planned transport route, and by considering the number of independent journeys required to deliver the desired amount of goods by the selected transport means.

The additional accident risk due to “empty travel” of the transport mean(s) used may be also considered and added to the risk figures for the overall transport assignment. In the prototype the user can assign a percentage value in relation to the route length to represent the amount of “empty travel”. This additional exposure then becomes also accounted in the overall risk figures for the transport case. Different percentage values can be assigned to different route sections, e.g. consisting of different transport modes. As an alternative, the empty travel of the transport mean may be assessed as a separate transport task.
Also the risk of accidents in the various goods handling activities taking place in relation to the transport assignment can be considered. In the current prototype, goods handling is presumed to take place at the start and the end points of the transport, and at those nodes where the transport mode is changed. The corresponding risk figures are calculated automatically for these nodes based on the generic risk parameter values that have been initially assigned in the tool for different types of goods handling.

The specific risk results calculated for a particular realization (i.e., specific route and conditions) of the given transport assignment may be compared to general risk levels for the same transport calculated in parallel, and to risk results calculated separately for some alternative realizations (i.e., different modes, route and/or conditions) of the given assignment to guide planning of safer freight transports. The general risk levels for a transport are calculated taking into account all possible conditions and represent risk reference levels against which a particular transport plan can be compared. Risk informed transport planning should systematically promote such plans for which the assessed accident risk is lower than the corresponding risk reference level. In the long run this would reduce the risk of accidents in freight transport overall.

3.5 User interfaces

The prototype tool user interface consists of five main components as illustrated in Figure 3:

1. the main map window for defining transport nodes (i.e. origin, destination, intermediate) and for visualizing the route selection,  
2. data input form for defining the freight to be transported and selecting the vehicle types to be used,  
3. data input form for defining the routing criterion, and the transport conditions on each transport section,  
4. risk calculation results table to document the calculated risk figures for the overall transport assignment,  
5. save and load –function for transport cases (Only the necessary parameter values on the transport case and route that allow repeating the risk calculations are saved in a case file.)

In addition, the risk calculation results table (and the intermediate link results table) can be exported to other applications, e.g. MSExcel, for further processing or reporting.
4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The constructed prototype tool has shown that the specified risk assessment approach is feasible for the assessment of accident risks in freight transport. The risk figures produced support the comparison of transport alternatives.

The collected and reported data available on the Finnish public main road network, the freight traffic flow rates and the injury accidents occurred on heavy vehicles provided a proper basis for implementing the proposed risk assessment concept for road transport. The lower quality of the data that was readily available restricted full implementation of the tool in relation to railroad and waterway transports, and freight terminal operations. Only generic risk parameter estimates could be provided in the prototype for these cases to support the risk assessments.
The prototype tool was developed in particular for assessing freight transport in Finland. However, the implemented risk assessment concept and the system architecture are seen valid also for “localisation”, i.e. for use in other geographical areas. Such localisation can be done by changing the network models, and the network use data and the accident data to represent the new application. Availability of suitable local data is an obvious prerequisite for this.

Studies still need to be performed investigating the reliability of the accident risk assessment results produced by the prototype tool. This is necessary to validate the tool, and to capture the confidence of the tool users on the risk figures presented as point estimates.

Further development of the current prototype tool into a real maintained tool is currently discussed. This could include a web-based implementation where the tool could be taken into use through a web-browser. Alternatively, one could consider if it would be possible to integrate the developed accident risk assessment routines and the risk data into some existing tools used for transport planning.