ABSTRACT

The paper presents an integral system for monitoring the conditions on the dangerous sections of the Slovenian road network. The data includes roadway geometry, objects on and along the roadway, friction properties, mechanical properties of the measuring vehicle, mechanical properties of human body as well as collected data about driver behaviour. Also included are the data on previous security-related events on the analysed road sections as collected by the police. The collision simulations and the simulations of driving dynamics were partly performed by software tools developed by the authors and partly by commercial software tools. The data acquired from measurements and research, together with the simulation results, are organised in a "dangerous road section database". A software application has been developed to manage the data in this database and view it in different forms. It includes a video player module for easy reviewing, adding and editing the data about the objects on and along the road and tools for searching the database using different criteria.

1 INTRODUCTION

Monitoring the data about conditions and events on road sections identified as dangerous, also referred to as "Black Spot Management", has been an active field of traffic science in Europe in the last few years [1, 2, 3]. It is essential that the activities in this field have proper information technology support. This should include tools for identifying the dangerous road sections (or "black spots"), tools for gathering and managing the data about them and tools for help in suggesting the measure for improvement of conditions.

The goal of the work presented in this paper was to develop a system that would centrally join and interconnect all the data, available on particular dangerous sections which are identified as dangerous by various criteria, and provide a software application for viewing and managing the data in a user friendly manner. Since many pieces of data about road sections are not readily available, the system should also include all the support tools to acquire, convert and store those data. The structure of the system with its main elements is schematically shown in Figure 1.
DATA STRUCTURE

The data about dangerous road sections are organised into a relational database. The working entity is a "dangerous road section area" of road sections as the connected dangerous road sections can be administratively assigned to different roads. The data are divided into the following groups regarding its origin:

- measurement results,
- data files containing digital video,
- simulation results,
- technical analyses,
- traffic safety related data, acquired and published by authorities.

The data containing road properties and digital video (from cameras inside the vehicle and from an eye-tracking device) are acquired on each particular road section. Afterwards the measured geometrical properties of the roadway are used in simulation of possible accident scenarios on the road section. These are then used to prepare technical reports that are also included in the database.

The database also includes the road network data (geometry, section designations, topographical data, axis geometries) maintained by Slovenian Road Agency and the data about past safety-related events on the road network collected and maintained by the Police.

MEASUREMENT OF SYSTEM PROPERTIES

In order to acquire the data about a particular road section on-site a measurement system has been set up. The sensorics for measurement of roadway geometry, its friction properties, for video acquisition and eye-tracking, together with a system for data acquisition and storage, are mounted in an ordinary passenger car (Figure 2).
3.1 Roadway geometry measurement and video acquisition

Geometrical properties of the roadway are measured during a normal ride of the measurement vehicle along the road section. Using an inertial measurement system (IMS, shown in Figure 3), the trajectory of the vehicle and the lateral angles of the vehicle body are measured. The IMS is supported with a contactless distance and velocity sensor, which helps minimise integration error and with a GPS receiver that helps determine the exact geolocation and initial heading. The vehicle body tilt in curves is compensated with additional accelerometers that measure lateral acceleration. Simultaneously with measuring roadway geometry a digital video from two cameras inside the vehicle (Figure 3) is acquired. The video frames are precisely synchronised with roadway geometry readings in order to evaluate features and quantities along the road axis.

Acquisition of the road geometry data and video is controlled by a measurement engineer in the measurement vehicle through a specially developed GUI application which runs on the measurement computer and controls all the relevant parameters of the measurement system.

The result of the road geometry measurements are data files with point coordinates, estimated roadway width and lateral inclinations in each measured point along the road section. Video frames are stored in separate timestamped files for easy access by viewing and editing software.
3.2 Human eye tracking

Human eye tracking is used to determine the gaze direction of drivers while driving along the road sections. This way it is possible to determine points of detraction and parts of road sections with reduced or impaired visibility. It is also possible to estimate visibility distances on critical parts of the road sections.

Due to computing power requirements eye tracking videos are recorded and processed on a separate dedicated computer system (Dikablis Cable [7], shown in Figure 4). To be able to position the eye tracking videos in space and time, the recording start time can be synchronised with the main measurement computer clock.

![Figure 4: Dikablis Eye-Tracking system (left) and its control application (right)](image)

To take into account the variations between different sets of parameters (different drivers, different cars, different time and weather conditions, etc.), it is possible to record multiple eye-tracking videos on the same road section and connect them to its entry in the database.

4 SIMULATION

4.1 Preparing the measurement data

Simulation results are used to assess the conditions on actual roads, which is why the simulation input data have to conform to the actual data measured on the road sections. To be used in simulations, the measurement results have to be processed and converted into a suitable form. To keep the simulation results consistent this has to be done by a unified procedure using software tools and as little user intervention as possible. To achieve this, a set of software tools [4] have been developed to convert raw geometry measurement data into a mesh model of roadway (Figure 5). The conversion is done in two steps. In the first step the raw data is converted into a file with axis points and inclinations, in the second step, this file is converted into a 3D geometry file in one of the formats used by simulation tools (RDF, DXF, VRML2).
4.2 Driving dynamics simulations

Driving dynamics simulations are performed in order to determine the safe parameters of driving dynamics on particular parts of road sections. This includes safe speeds for driving through curves, safe speeds for stopping in intersections, safe speeds of driving over various obstacles on the roadway and safe trajectories of passing the narrow road sections.

The simulations are done on models of actual road section surfaces obtained as described in 4.1. Different simulation tools are used for different tasks. ADAMS simulation package [8] is used to determine safe speeds in curves and loads on vehicle components while driving over obstacles. PC Crash [8] is used in studies of vehicle passing and braking in intersections, and i3Drive [5] is used in visibility analyses (Figure 6) and vehicle trajectory studies.

![Figure 6: Visibility analysis in i3Drive from inside a vehicle (left) and from a stationary point (right)](image)

The tools are used to determine safe driving dynamic parameters for different road conditions. These depend on weather, time of day, traffic density, and objects in the immediate surroundings of the road. The calculated safe parameters are recorded and can be presented in numerical or graphical form to the user of the system. These values are used to set the speed limits and propose other measures on existing road sections, or suggest reconstruction of the roadway or related objects.

4.3 Interactive driving simulations

For the convenience of the user the system also offers interactive driving simulations of various types of vehicles on the models of actual road sections. The i3Drive software tool in
interactive mode is used for these simulations and the results can be used by the user to quickly assess the safe driving parameters and to gain an additional overview of the road section. The simulation results can be recorded and presented afterwards as numerical data, charts or 3D animations.

4.4 **Simulations of typical accident scenarios**

Simulations of typical accident scenarios are performed to determine the loads on occupants and vehicles in typical accidents on the parts of road sections. The accident scenarios are partly derived from the police records on past events on the critical road sections and partly from the observations and video recording on actual sites.

The simulations include several types of collisions between two or more vehicles (frontal impacts, side impacts, rear impacts, roll-overs), collisions of vehicles with pedestrians and collisions of vehicles with objects near the road.

The tool used for collision simulations is PC Crash. The results are presented to the user of the system as numerical data, as charts of dynamics values and as 2D (Figure 7) or 3D animations.

![Image](https://via.placeholder.com/150)

**Figure 7: Three-vehicle collision analysis in PC Crash on a mesh model of a roadway**

4.5 **Human body load simulations and injury estimation**

The results of impact accelerations from crash simulations are used to simulate and analyse the loads on human body in the accident and thus estimate the injuries. To simulate the human body, the human body model developed at KmTM [6] was used. After the loads on critical human body parts are calculated, the injury criteria [6] are used to estimate the severity of injuries in particular crash scenarios. An example head acceleration time series together with neck injury criteria (NIC) time series in a typical rear-end collision accident is shown in Figure 8.
5 SOFTWARE APPLICATION FOR DATA MANAGEMENT

To centrally manage the data about dangerous road sections, a modular software application has been developed. It is designed to run on standard personal computers and can be used at different user levels: system administrators have permissions to add data and define new dangerous road section areas, object cataloguers have read-write access to roadway object database, medium-level users have read-only access to existing data and can search and display the data, while field crews have access to GPS module to allow them to record missing road axes.

Most of the end user tasks in the application are performed through intuitive and easy-to-learn graphical user interface. The modularity of the application allows the developers to make adaptations of the existing modules to user needs or add new ones with the shortest possible lead time. The modules are interconnected and the data is exchanged between them during normal flow of operation of the application. Most of the modules have their own dedicated parts of user interface that are presented to the user as application windows. Depending on the task being performed, the user can open as many module windows as required.

5.1 GIS system

The main mode of data management is its display and editing on map layers in the map module (Figure 9). This is the intuitive way and is possible since all the data in the database have a known geolocation. The map layers include topographic maps in different scales (1:250,000 to 1:50,000) and orthophotographic layer (1:5,000 scale). The data from the database is laid out over the map layer in form of points (e.g. road objects, past events on dangerous road sections), curves (e.g. road network and administrative borders) and surfaces (e.g. settlement area and dangerous area bounds). The data on the map is grouped into layers based on its type. The layer manager allows the user to display or hide each individual layer according to the required task.

Each entity displayed on the map offers the user a menu with the tasks available for the selected entity and context. This way the map module is linked to other application modules.

The data about dangerous areas is edited in a special Dangerous Area Data Editor module window with a tabbed interface representing individual groups of data (Figure 9).
Figure 9: BSM application main window with map module and Dangerous Area Data Editor

5.2 Video Player module with roadway object management tools

Recording the video while driving over a road section is an efficient way of documenting the conditions on the road section and in its immediate vicinity. A video from two vehicle mounted cameras is recorded during measurement of road sections as described in 3.1. To be able to use this video and recorded driving dynamics data, a special Video Player module (Figure 10) has been developed. Apart from playing the video from the two cameras, it also synchronously displays the measured kinematics data (velocity, acceleration and angular velocity in three axes).
Figure 10: Video player module

The video player module is also connected to the roadway object database and displays the roadway objects (signalisation, infrastructure obstacle etc.) as the video is played. Object properties can be edited and new objects added by the user without leaving the Video Player module. Types of common objects and objects that are standardised (e.g. vertical traffic signalisation) are available for the user to choose from predefined object templates.

5.3 Search and query module

The flexible search and query module allows the user to search the entire database or its parts for data using various search criteria or database queries. Depending of the nature of the search criteria, the search results are available as numerical or text data or displayed on the map.

Based on search results the system can help the user to prepare reports in various text and graphics formats for distribution and further analysis.

5.4 GPS module

When used in the field, the BSM application can be connected to a GPS receiver, which provides a real-time geolocation of the measurement vehicle. The GPS module provides possibility of recording the vehicle trajectory and placement of roadway objects on it. This is useful when cataloguing newly built roads or roads that have undergone major renovations.

6 CONCLUSIONS

The presented work is a step towards a central Black Spot Management system developed to enable its users to manage the data about dangerous road sections on an area of
arbitrary size. The proposed database structure allows storing the timeline of all the relevant data from various sources. These combine own measurements and observations with data on past events and results of simulations and analyses.

The software application that has been developed to support the database enables the user to accomplish the tasks of data management, display, review and export from a graphical user interface. The modularity of the application grants its adaptability and expandability. The system is currently being introduced into operation at the Slovenian Road Agency.

REFERENCES


