Monitoring and Decision Support System for Traffic Safety on Bridges[1]

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Abstract

This paper discusses the development of monitoring and decision support system for traffic safety on a long road bridge using a fuzzy inference module based on the Mamdani algorithm. The proposed model allows the user to get a recommendation remotely about the ability to move across the bridge.

Keywords

Monitoring system, decision support system, fuzzy logic, data base, traffic safety

1. Introduction

The development of a modern road transport network makes it necessary to ensure the safety of movement, especially with regard to such strategic structures as bridges. The problem of monitoring such objects is complex and includes the following tasks: measuring the key characteristics of the objects themselves and their physical and technical characteristics.

Here, different measurements are at the centre. For bridges, it is the measurement of meteorological parameters (primarily wind direction and speed), the determination of the state of the road down which transport is coming, and the strength of the bridge structure supports.

In turn, the Decision Support System (DSS) should provide the driver with free and timely access to critical information, in a form that he understands, that will ensure the safety of his driving.

It focuses on methods of interpretation of the data obtained by the decision support system, as well as technologies that allow the user to acquire knowledge from any geographic location.

2. Determination of the Basic Characteristics of Traffic Affecting Safety on the Bridge

2.1. Basic characteristics of the bridge environment and means of measuring them

The main weather conditions affecting the safety of traffic on the bridge are the wind (its speed and direction relative to the object), as well as the condition of the carriageway on which the vehicles are moving. The relevant sensors (anemometer, temperature sensor, road surface sensors) are used to measure these parameters and have been discussed in details in [1].

Consider in more detail the main meteorological characteristic for the bridge transition - wind speed and associated wind pressure.

Wind pressure and wind strength. An automobile passing through a bridge is exposed to the air, and the higher the speed of the flow, the more the vehicle deviates from the trajectory. The main danger when driving on open ground (including on a bridge) is the side wind, which operates perpendicular to

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the movement of the car**.** In a gushing wind, the car shifts away from the trajectory under the influence of the wind and returns under the control of the driver, making the vehicle erratic.

The calculation of the wind load shall take into account both the wind speed and the dimensions of the vehicle and the height of the bridge clearance [2]. The wind power may be calculated by the formula:

$$F = V^2 \bullet \frac{\rho}{2} \bullet C_x \bullet K_\pi \bullet (1+\varepsilon \bullet m) \bullet S \text{ (N)}, \quad (1)$$

where V is the wind speed, which characterizes the disorderly stochastic nature of the wind pulsation in the ground, allowing the distribution of the wind flow to be considered to be subject to the normal distribution law, m/s;
ρ is the density of air depending on bridge clearance height, temperature, pressure and air humidity, kg/m^3;
C_x is an aerodynamic drag coefficient that shows the degree of aerodynamic stability. This factor is 0.75 for side-wind resistance;
m is the rate of pulsation of the velocity pressure, which takes into account the dynamic action of gusts of wind, determined by climatic conditions, topography of the terrain, altitude of the object;
K_π is a correction factor for elevation of velocity pressure, which determines the uneven vertical distribution of wind speed;
S is the area of application of the wind load equal to the surface area of the vehicle;
ε is a dynamic factor that takes into account the reaction of a car to wind pulsation.

Grip for the road surface. The coupling properties of road surfaces, which are most dependent on the state of the surface of the pavement, are characterised by the coefficient of adhesion k, which takes the values for asphalt from 0.7 (dry cover) to 0.1 (black ice) [3].

The grip of a vehicle affects its stability in motion and the safety of manoeuvres. The main force preventing the vehicle from being shifted by wind forces is the friction of the wheels on the road:

$$F = k \cdot mg \text{ (N)}, \quad (2)$$

where k is the slip coefficient, depending on the condition of the road track;
m is the mass, kg;
g is the gravitational constant, $m^3/kg \cdot s^2$.

Four main road conditions can be defined according to weather conditions: a dry road, a wet road, a snowy road (slush) and a flood.

2.2. Additional factors affecting traffic safety

The width of the road and the permissible shift of the car. The width of the lane as well as the dimensions of the vehicle itself determine the amount of free space (gap) between the edge of the strip or line of markings and the side of the vehicle. This gap defines the permissible shift of a vehicle in motion without creating an emergency situation, both for the driver of the vehicle and for other road users. For most of the transport bridges studied, the lane width is 3.5 – 3.7 meters.

Therefore, the allowable gap between the vehicle and the edge of the strip (Fig. 1) is calculated by the formula [3]:

$$Y_{add} = \frac{(L-W)}{2} - C, \quad (3)$$

where L is the width of the lane, m;
W is the track width of the vehicle, m;
C is the minimum value of the approach to the edges of the lanes.

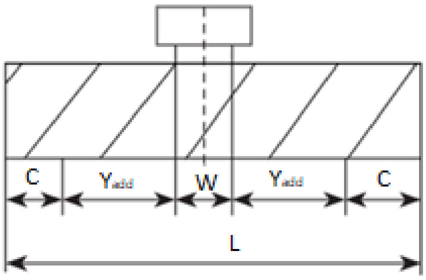

Figure 1: Design diagram for determining the tolerable deviations of Y_{add} car during winds

If the possible deviation exceeds the calculated permissible value, this may lead to a pull-out or an adjacent lane, thus endangering the motorist and other traffic participants.

Calculation of the shift value of a car under the influence of the side wind. Based on calculations of the wind force, the counteracting friction force of the wheels of the vehicle, and taking into account the reaction time of the driver, it is possible to calculate vehicle shift from the trajectory of the way during the journey (Fig. 2).

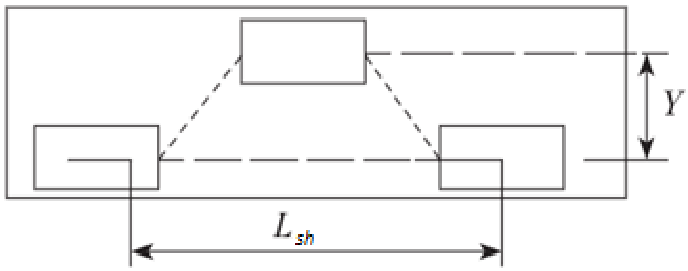

Figure 2: Vehicle shift from the trajectory due to side wind

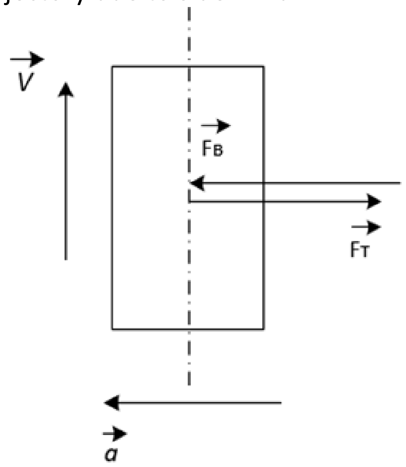

Figure 3: Driving forces in the side wind

In order to determine this value, it is necessary to determine the wind force at which the friction is no longer preventing the vehicle from shifting, resulting in lateral acceleration (Fig. 3). Knowing the acquired lateral acceleration of the car as well as the driver’s reaction time to the manoeuvre, the total deviation Y can be calculated using:

$$ma = F_{\text{B}} - F_{\text{T}} \text{ (N)} \tag{3}$$

$$Y = \frac{at^2}{2} \text{ (m)}, \tag{4}$$

where m is the mass of the car, *kg*;
a is the acceleration obtained by the vehicle under external forces, m/s^2;
F_B is the wind force that displaces the vehicle, *N*;
F_T is the skid force preventing the vehicle from being displaced by wind, *N*;
Y is the amount of vehicle shift from the trajectory of motion, *m*;
t is the driver’s reaction time to a manoeuvre, *s*.

Using (3) and (4), it is possible to determine the expected deviation of vehicles of different dimensions and masses due to wind forces depending on the length of time of the driver.

Classification of cars by size. In order to build a decision support model for traffic safety, it is necessary to define the key characteristics of the vehicle that influence its movement under different weather conditions and to classify the total amount of vehicles into a limited number of categories.

All cars vary in size, as well as in curb weight and in gross weight.

In this work, the authors have decided to define five main and two additional categories, as presented in table 1.

Table 1
Vehicle categories

Category	Description	Board square, m^3	Weight, tons
1	Class A-F cars and SUVs	7,00	1,6
2	Small cargo vehicles such as GAZ-2705	12,00	2,7
3	Medium-sized trucks (dump trucks) of large dimensions, such as KamAZ-65222	29,00	11,35
4	Heavy goods vehicles of large dimensions such as KamAZ-65117	42,00	15,00
5	Regional passenger buses such as NEFAZ 5299-37-32	45,00	18,00
Additional 1	Loaded medium trucks (dump trucks) of large dimensions, such as KamAZ-65222	29,00	25,00
Additional 2	Heavy goods vehicles with large dimensions such as KamAZ-65117	42,00	27,00

3. Architecture of the Decision Support System

To be feasible, the model requires an external user-friendly interface, a continuous extension and modification of the regulatory framework, as well as a reliable and continuous connection to the traffic flow on the bridge [4]; shall accumulate and maintain knowledge of the ever-expanding family of vehicles; shall be scalable and available to several users from different geographical locations simultaneously.

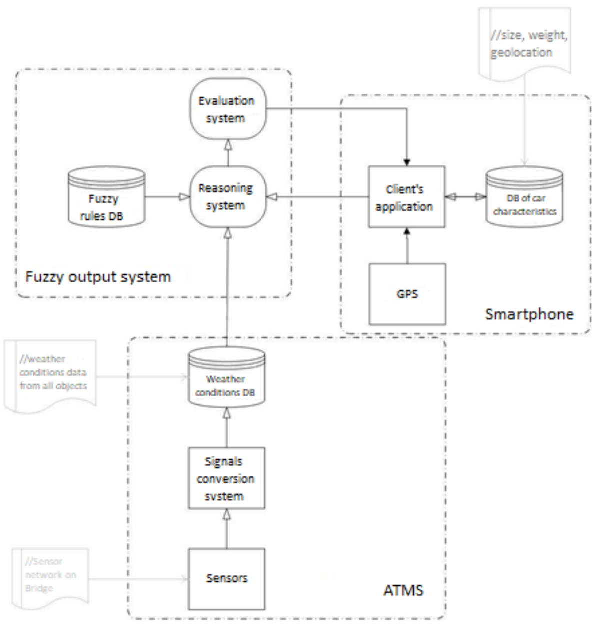

Figure 4: Software and hardware of the monitoring system

The hardware and software of the monitoring system (Fig. 4) is composed of the following subsystems:

- The Automated Traffic Management System (ATMS) is a set of sensors installed over the bridge, a sensor signal reading and processing subsystem and a continuously growing database (DB) of weather conditions on the bridge;
- A fuzzy output system representing a set of fuzzy rules and a fuzzy output algorithm;
- A mobile user platform connected to a fuzzy output and DB of car characteristics by means of a special application.

The sequence of operation of the complex is as follows (fig. 5):

1. Using the application, the user specifies for the system which car he is driving, his driver experience, and his geographic location and route.
2. Using the DB of cars characteristics, the application sends the characteristics of the user’s car to the input of the fuzzy output system.
3. According to the user’s route data of the state of bridges through which the route passes are sent to the input of the fuzzy output system.
4. On the basis of fuzzy rules and input data the safety for the user of all bridges lying on the route is calculated.
5. The user’s application sends recommendations to change the route according to the calculated safety of bridges lying on the route.
6. The received recommendations are displayed on the screen of the user’s mobile device.

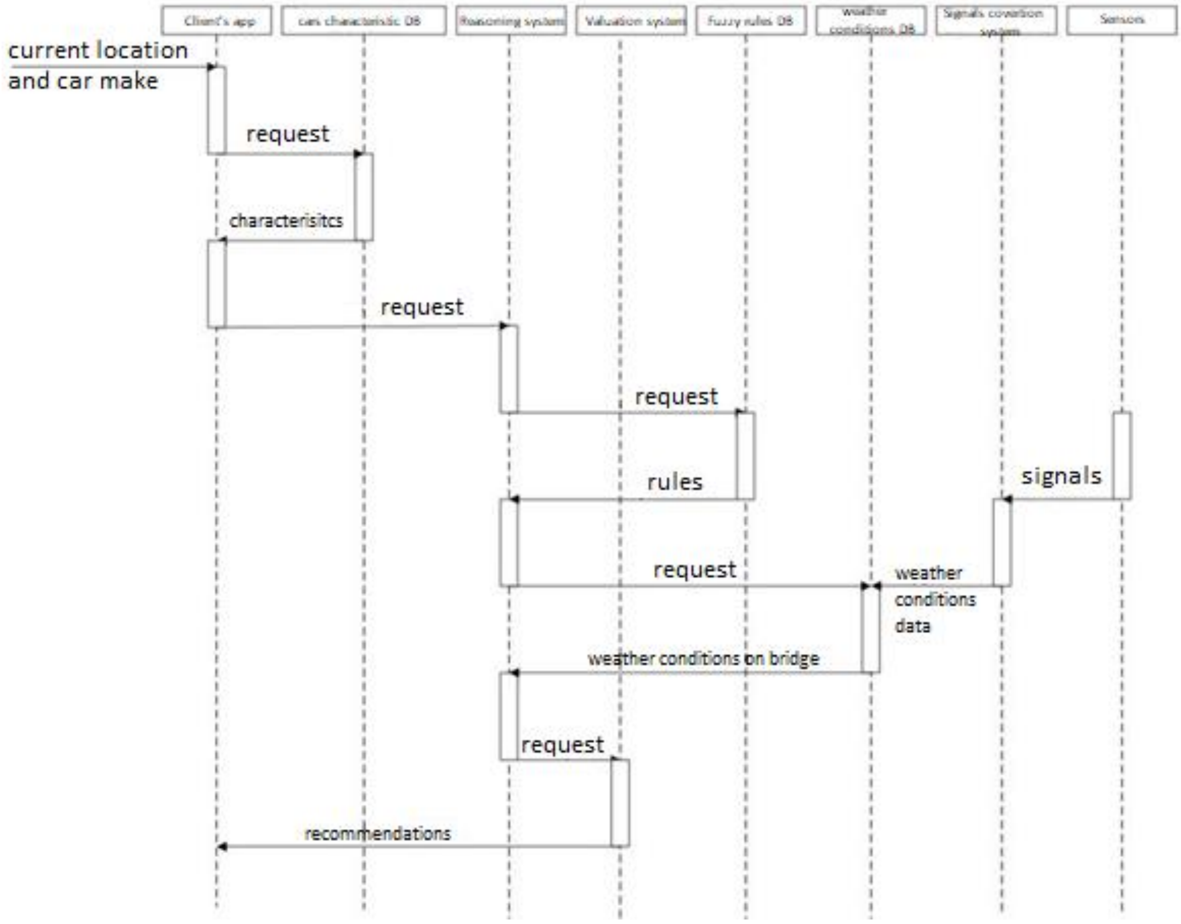

Figure 5: The Recommendation Output Sequence Diagram

In order to supply the necessary data to the inputs of the fuzzy output module, it is necessary to retain the transformed sensor signals located on the transport bridge on which traffic safety is to be determined. A bridge weather conditions DB has been developed for this purpose.

3.1. Weather conditions database

The database consists of 5 tables: 3 source tables with converted sensor signals, a register table with bridge data and one integration table for aggregation of data 3 tables-sources and sending them to the fuzzy output system.

The source table «Wind» contains information on speed and wind and speed of its change, as well as the height of the sensors throughout the bridge at the specified time. The table accumulates data that are transformed signals from anemometers installed along the bridge.

The source table «Temperature» contains information about air temperature throughout the bridge at the specified time. The accumulated data are transformed signals from temperature sensors located along the entire bridge length.

The source table «State of Road» contains information on the state of the road surface and its temperature throughout the bridge at a specified time, as well as the value of the width of the road lane fixed for a specific bridge. The accumulated data are transformed signals from Road Surface Sensors (RSSs) located along the entire bridge length.

The Reference Table «Bridges» contains information about bridges on which traffic safety monitoring is carried out: name, position coordinates, height of overflight, width of traffic lane.

3.2. Data processing

The operating principle of the weather database is as follows. Converted to data signals from sensors located on the transport bridge are recorded in the source tables «Wind» (WIND), «Road Condition» (RoadCover), «Temperature» (TEMPERATURE) every 10 seconds (fig. 6).

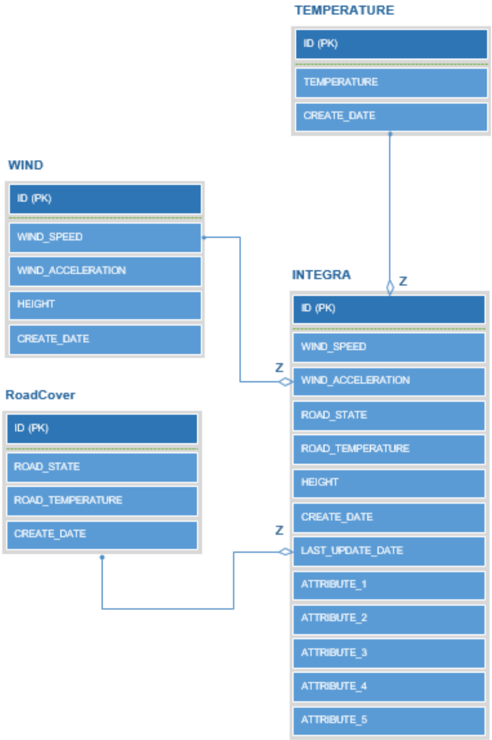

Figure 6: Database model in IDEF1x notation

Further, every minute, according to the aggregation procedure, data from source tables are recorded in a common integration table for further transmission of data to the fuzzy output system. The last recorded entry is taken from each source table.

In order to control the amount of data, the database has a procedure for cleaning records from source tables and integration tables that exceed 60 minutes, allowing for the use of limited disk space.

3.3. Fuzzy Output Module Development

Fuzzy output systems are designed to convert input variables of the control process to output variables using fuzzy output rules [5, 6]. For this purpose, fuzzy inference systems should contain a basis of fuzzy production rules and implement fuzzy inferences based on assumptions or conditions presented in the form of vague linguistic statements.

The basis of the system of fuzzy production rules is the linguistic variable (LV) «Wind speed», created on the basis of the twelve-sided Beaufort scale adopted by the World Meteorological Organization for the approximate assessment of wind speed [7].

Table 2 presents a fragment of the regulatory framework of the support model for decision-making on restricting traffic on the bridge according to weather conditions [1].

Table 2
Fuzzy production rules for restricting traffic on the transport bridge

Terms for LV «wind speed»	Production rules
Low	IF wind speed = Low THEN motion = Permitted
Average	IF wind speed = Average THEN motion = permitted
	IF wind speed = Average AND wind velocity = increasing AND road condition = icy THEN motion = slightly forbidden
Strong	IF wind speed = strong AND wind velocity = unchanged AND road condition = icy THEN motion = slightly forbidden
	IF wind speed = strong AND wind velocity = slightly increasing AND road condition = icy THEN motion = strongly forbidden
	IF wind speed = strong AND wind velocity = increasing AND weather condition = icy THEN motion = forbidden

4. Components Implementation Based on Microsoft SQL Server 2012 and JavaScript

4.1. Weather conditions database

The weather conditions database is implemented on Microsoft SQL Server 2012. The database server DESKTOP-NRO7L47 SQLEXPRESS (fig. 7) has been started to create and configure the database. The SENSOR_RESULTS_DB weather conditions database is designed according to its data model described in the previous section (fig. 8). The tables are pre-filled with test data.

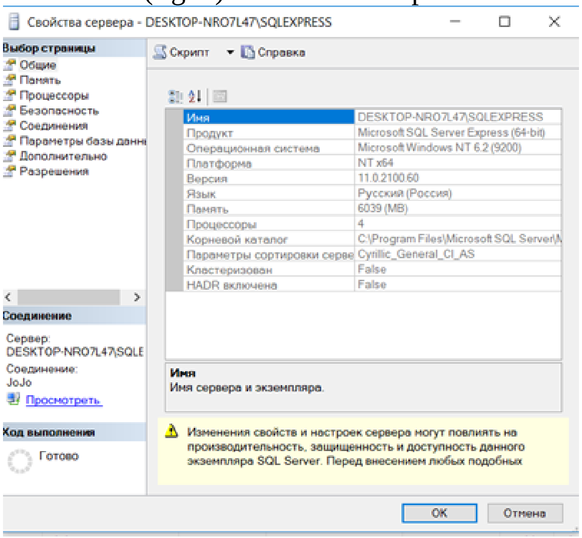

Figure 7: Database Server Properties

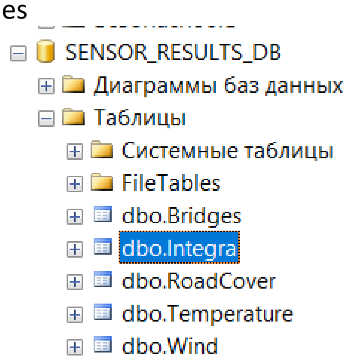

Figure 8: Structure of the weather condition database

4.2. Sensors data generator

The source of the input data is a data generator which simulates the insertion of the data of the converted sensor signals into the source tables. The generator runs once in 30 seconds, filling in the data of the tables Wind, Temperature, RoadCover.

The data generator is a separate independent program written in JavaScript (listing 1).

When the program is started, it automatically connects to the weather database according to the specified parameters and inserts rows into the database tables according to its own code. Similarly, the procedure of aggregating data from source tables into an integration table is implemented in the form of a separate independent program in the language JavaScript. Like the data generator program, the aggregation program automatically connects to the database and then, according to the logic in the program code, completes the Integra integration table with data from source tables.

```
package Generator;
import java.text.SimpleDateFormat;
import java.util.Calendar;
import java.util.Random;
public class GenerateData {
    public float T = 0;// temperature
    public float W = 0;// temperature
    public String Generate(String type, int n) {
        switch (type){
            case "T":
                return Temperature(n);
            case "R":
                return RoadCover();
            case "W":
                return Wind(n);
            case "I":
                return UpdIntegra();
            default:
                return "Error! There is no type" + type;
        }
    }
}
```

Listing 1: GenerateData Class Declaration

4.3. Cars database for client application

In order to provide information to the user on the possibility of his vehicle moving on the bridge on which the monitoring is carried out, the client application must have a database of vehicles characteristics, from which the user will be able to choose his car model and specify it in the application. The database should also store and process data on the driver. Like the weather database, the DB of car characteristics is also implemented by Microsoft SQL Server 2012, based on the DESKTOP-NRO7L47 SQLEXPRESS server. The database itself is called DRIVING_SAETY_APP.

4.4. Module implementation in Matlab

The Fuzzy Bridge Traffic Restriction Reasoning Module, developed in Matlab, uses a fuzzy Mamdani output algorithm [1]. When receiving input data from the DB of weather conditions and the DB of of vehicles characteristics, the module converts them into recommendations for limiting traffic on the bridge along the user’s journey by means of a developed base of fuzzy rules.

5. Conclusion

The prepared work includes the conditions affecting the safety of traffic on bridge crossings and the means of their measurement, the formulas of calculation and the table of rules for the wind force influencing cars under different weather conditions on the bridge, the schema of the software and hardware system for monitoring and decision support for traffic safety on the bridge is proposed.

With the use of database and software development tools, a weather DB and a client application DB have been developed, as well as a random sensor data generator to test the operation of the weather database.

6. References

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