Development of a database for information support of virtual digital analysis in design and testing of road infrastructure elements

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Abstract. Ensuring traffic safety on the roads and reducing the number of deaths due to road accidents is a priority task both in Russia and in the global community. Assessment of safety in the event of vehicle crashes, oncoming lane exits, collisions with road barriers and other elements of the road infrastructure (ERI) requires the use of a wide range of modern and innovative information technologies - special environments for automated design of Digital Twins of road infrastructure elements, virtual tests with collision modeling and obtaining results on different input parameters of the simulation, modern automated testing of the road infrastructure elements. All these practical works, research and development are carried out at MADI together with scientific team LLC M&PQ to improve road safety. The article deals with the prospects of development of these works, a natural transition to another level of research. Based on the intellectual technologies in the field of road construction, work has begun on creating a special information environment, the so-called "Virtual Digital Proving Ground", and, among other things, to provide it, a database (DB) of computer-aided design and virtual testing of digital models ERI, which will improve the efficiency and quality of work. The use of the ERI database will allow to implement the automated control of the developed ERI digital models, to implement tools for designing new innovative structures, to predict the behavior of accident participants, to develop reasonable standards in the field of road barriers of the future, to carry out examination by requests of various organizations.

1. Introduction

Russia’s economy today faces the most complex task of transition to a fundamentally new technology of "digital economy" in terms of its scale and content, the fundamental feature of which is the unification of material and digital (virtual) worlds. Solving this global problem requires the development of fundamentally new business processes, automation and intellectualization in all sectors of the economy, leading to a systematic approach to solving the problems of the economy as a whole. A fundamentally different approach to the development of the country’s transport system requires priority development - the industry faces the challenge of developing, implementing and operating a single intelligent transport system that will provide domestic companies with effective and safe interaction to create products and services that are competitive on the world market.
The implementation and functioning of a single intelligent transport system includes the solution of many tasks, we will focus on the most important ones.

"Road digitalization" requires the development of special information support that will allow to store data for the description of the location, size, construction and technical characteristics of roads, their structural parts, elements of engineering and artificial structures, as well as their changes during the life cycle of the road. Such direction can be conventionally called GIS-modeling (GIS - geoinformation system - a system for collection, storage, analysis and graphical visualization of spatial (geographical) data and related information about the necessary objects) [1].

The second direction, which has been widely developed in recent years, is the evolution of computer-aided design (CAD) systems into the concept of information modeling of capital construction objects (Building Information Model - BIM) [2]. BIM technology is understood as such an approach to the life cycle of the modeling object, at which the information model gathers and stores all the necessary design, technological, economic and other necessary information about the components of the interrelated elements of the modeling object. When using BIM, information about the model allows one to automatically create drawings and reports to perform analysis of the project, manage the operation of the object, etc., providing unlimited opportunities for management decisions [3].

Both directions require the development of special information support for solving the problem of storing large volumes of both structured and unstructured data in one way or another. Just as the very concept of a single transport system includes a set of components interconnected with each other, but which can be considered and studied separately, so the information support is more effectively developed for individual system components with the possibility of further integration into a single information space of a single intellectual transport system [4].

Since 2010, scientific and practical work has been carried out in the Moscow Automobile and Road State Technical University (MADI) by the staff of the Department of Construction Mechanics and later, by a small innovative enterprise (LLC M&PQ) - on the problems of road safety regarding elements of road infrastructure (ERI), which the safety in case of traffic violations depends on. These are various types of road safety barriers, lighting supports, signs, advertising supports, crossings, acoustic panels, anti-tank devices etc. In a relatively short period of time, the MADI team, together with LLC M&Q, developed a methodology for virtual computer analysis of crash situations and crash-tests when vehicles collide with road infrastructure elements, as well as the digital models of wire rope safety barriers, concrete safety barriers, frontal barriers, mobile frontal barriers and other types of road infrastructure elements. More than one thousand virtual tests (crash-tests) of specific ERI objects were carried out on orders of industry enterprises. Methods and scenarios of virtual testing were developed in accordance with the relevant regulatory documents [5]. Virtual testing is now an increasingly important part of the road safety system. The application of virtual testing in assessing compliance with safety requirements, such as road barriers, has now become part of EU, US and EurAsEC road barrier standards. Our accumulated experience makes it necessary to switch to new innovative information technologies in the field of road safety through the automation of ERI design and testing. Such technology should be the development of a special intellectual environment - the information system (IS) of the Virtual Digital Proving Ground for crash testing against vehicle restraint system. This article deals with the development of a database (DB), which should become the basis for the information support of the "Virtual Digital Proving Ground for crash testing against vehicle restraint system".

2. Models and methods of information support development for the "Virtual Digital Proving Ground".

To develop the structure of the database it is necessary to perform the following actions:

- to set design requirements,
- to analyze and formalize these requirements in the form of development tasks;
- to build an information model of the process of performing these tasks in reality.

Tasks, which the developed database should provide with all necessary data:

- development and analysis of new digital ERI models (DM),
modeling of new digital models of road infrastructure elements with the ability to vary the elements of design and materials;
comparative analysis of virtual and field test results;
change of test conditions due to variation of parameters;
prompt control over compliance of virtual tests performed with regulatory documents and developed methods;
verification and validation of digital models and test results.

To build an information model of the process, we will call it the "Virtual Digital Proving Ground", we will use the Business Process Management Notation (BPMN) method, which has proved to be a perfect method for improving operational activity and visualizing the process in conjunction with explicit business rules and operational and technical requirements. Figure 1 shows the resulting model.

Figure 1. Information model of the main process of virtual testing with the help of the created "Virtual Digital Proving Ground"

Creation and analysis of the obtained model allows to reveal all necessary data to support the process and to form the database structure, which should store the description of information objects (Table 1). In the course of database design there was a problem of organizing storage of some data. When describing entities, it is necessary to define domains of each attribute. For the majority of attributes it is simple enough to do it, but a part of entities have attributes which should store design and drawing documentation of different types - construction and technical documentation, 3D-model in the accepted code, specialized files with extension .k. Examples of such data are shown in Figure 2.

Figure 2. Examples of data fragments for database storage: (a) - temporary fragments (or video) of the bus hitting the road barrier - file with the extension .k; (b) - 3D model in code, e.g. Solid Works, mobile frontal barrier (MFB); (c) - Fragments of a movie (video - file) showing a car hitting a road barrier during virtual tests - file with the extension .k
### Table 1. Description of entities

| Entity Identifier | Description |
|-------------------|-------------|
| **Staff** | Engineers and managers at different levels, other employees (under contract) |
| **Contract** | Contract with customer; Order from a counterparty; Internal task from laboratory manager to engineer; Supplement to the contract |
| **Customers** | Customer companies Counterparties Executors (as a customer) |
| **Elements** | Element (part) of a road barrier or other element of road infrastructure, for which there is a digital model |
| **Barriers** | Road design of any class, consists of the elements provided by the customer |
| **Vehicle** | A vehicle that is used as a collision vehicle in tests |
| **Road** | These roads (surface material, climatic conditions) in test |
| **Materials** | Materials of the elements according to the customer's standard and/or laboratory tests data |
| **Tests** | Virtual or field test data (list by test laboratory maintenance station) |
| **Application** | External document from the customer, on the basis of which the contract (laboratory form) is created |
| **ERI** | Elements of road infrastructure, except for barriers |
| **Method** | Methods of virtual testing (laboratory maintenance station) |
| **Parameters** | Calculation parameters (list of boundary conditions for the laboratory maintenance station) |
| **Protocol** | Laboratory document (form) for the performed tests of one contract and one barrier or ERI |
| **NormDoc** | Normative documents, according to which virtual tests are conducted (GOSTs, industry-specific road guidance documents etc.). |

Other entities have attributes where scans of important legal or technical documents, which are files with the extension .pdf, should be stored.

It is necessary to make a decision how to organize the storage of such files. DBMS SQL Server 2019 was selected as the target DBMS. In this DBMS it is more convenient and efficient to store files with the .pdf extension in a table with an attribute, the domain of which is varbinary (max) or image, but with the addition of an attribute that will store the pdf file name.

Organization of file storage with other extensions requires choosing one of the methods. There are the following ways to solve this problem:

1. Save such files in a certain file system location on the database server and a link to it - in the corresponding entity attribute (domain type - text or hyperlink). The approach under consideration has many flaws:
files are not deleted when deleting the corresponding database record (link integrity is not supported);
• a problem occurs while trying to update a file;
• violation of synchronization between the database and the file system when rolling back a transaction (transaction integrity is not supported);
• when backing up and restoring information in the database, asynchronization with the file system may occur;
• files are not subject to access restrictions imposed by the database.

2. Store files directly in the database, in a field with a domain of BLOB type (image, varbinary(MAX)). With this way of storing files, the following happens:
• database volume increase,
• database fragmentation,
• lower data processing performance.

There are special procedures for solving this problem in different DBMS. Their use will solve the problem of reducing the speed of downloading a file from the database, but does not solve the problem of increasing the database volume.

3. SQL Server 2019 DBMS features for storing large volume files - FileTable based on FileStream:
• easy handling of file names
• two-way link integrity
• guaranteed transactional integrity.

To make a decision, it is necessary to define the following parameters and their priorities in the interaction of users with the database of such attributes:
• file volume - 500 kB-3.5 mB on average
• need to work with the file and make corrections in the creation environment
• importance of file download speed.

![Figure 3. View of the file table directory on the server](image)

Files of technical drawings, 3D-models, specialized files with extension .k are rather advantageously stored in file tables, thus creating a storage of digital models, managed both from the database side and from the application side. An example of a directory of such file tables created is shown in Figure 3.

After the decision to store large volume files in file tables and perform all stages of database design, the database was implemented, a part of its structure (mainly related to the road barriers) is shown in Figure 4 [6].
3. Findings and results

The implemented database is the information basis for the creation of the "Virtual Digital Proving Ground" and will ensure the automation of all data handling processes. The advantages of working in such an intellectual environment are obvious: increasing the speed of search and processing of already existing 3D models, improving the performance and quality of new models created, conducting virtual tests, creating all necessary technical and report-related documentation and conducting validation analysis of the virtual results obtained.

The use of the "Virtual Digital Proving Ground" will increase the quantity and quality of the validation of digital models of road infrastructure elements, which gives us reason to consider the developed models as highly adaptive digital twins of ERI (ERI DT). The term "Digital Twins" is justified by a mandatory comparative analysis of the calculated parameters obtained during each virtual test with standard criteria. Necessity of such analysis of the received estimations of ERI digital twins is connected with the increased responsibility for the carried out ERI certification, which then provide safety of constructions installed on roads [7].

The important task, where the use of "Virtual Digital Proving Ground" possibilities plays a crucial role, is the task of reconstruction of road accidents. Digital simulation of possible collision situations of a car (initial speed, trajectory) on a road barrier and the variant analysis allow to reconstruct process of accident accurately enough and to define the reasons, a share of participation of a road barrier (or any element of a road arrangement), its elements and materials in absorption of energy of blow, indexes of damage for colliding cars and, what is not less important, for cars which have got on a way of its movement in a counter lane.

Figure 4. Structure of the "Holding side road barriers" database. (Vehicle Restraint Barriers (VRB))
Thus, the "Virtual Digital Proving Ground" will also allow one to create a digital twin of the accident (DT) with a blow on the road barrier on the basis of complete information about the accident [8].

Development of experimental research methods for validation of virtual digital models aimed at damping studies in structural elements, construction of refined mathematical models of materials and structural elements, full automation of modeling processes, design and testing of EDI models allow us to consider the software product "Virtual Digital Proving Ground" as a BIM technology and to use it in the future as an integrated part of BIM-model of a single transport system, which will solve the most important problem of developing road safety systems with the help of modern innovative technologies.

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