

GIS APPLICATION FOR MANAGING AND MAINTAINING ROAD NETWORK IN ULAANBAATAR

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Abstract

The paper describes an implementation of the project “The Quality Roads and Bridges – The Infrastructure Connecting People” in which Pavement Management System (PMS) for road network in Ulaanbaatar city has been developed. Pavement management decisions need to integrate diverse spatially referenced data, including condition surveys, construction history, skid resistance measurements, traffic counts, construction and maintenance records etc. GIS technologies offer appropriate tools to handle such kind of data. Experts from the University of Žilina have developed an effective methodology and tools for road network infrastructure management, reconstruction and maintenance. Project integrated geographic information systems technologies with the new developed Pavement Management System. New system serves for storing, retrieving, analyzing, and reporting information to help with a pavement-related decision-making process. The system works on network level and project level. The primary purpose of the network level management activities is to develop a priority program and schedule of rehabilitation, maintenance, or new pavement construction work within an overall budget. The length of the road network in this system is 420 km. The newly developed GIS system allows users to display visually the results of database queries and pavement management analyses on a map. Users can view network conditions and projected work programs. Integrated with graphs, tables, charts, etc., maps are very efficient in helping PMS engineers to communicate with politicians and other involved stakeholders.

Streszczenie

W artykule opisano realizację projektu “Jakość dróg i mostów – Infrastruktura łącząca ludzi” w Ułan Bator. Ekspersi z Uniwersytetu w Żylinie opracowali skuteczną metodologię i narzędzia do zarządzania infrastrukturą sieci dróg, ich przebudowy i konserwacji. Nowy system służy do przechowywania, wyszukiwania, analizowania i przekazywania informacji, tak aby pomóc w procesie podejmowania decyzji. Podstawowym celem działania było opracowanie programu i harmonogramu rehabilitacji lub budowy chodnika w ramach ogólnego budżetu. Długość sieci drogowej wynosiła 420 km. Nowo opracowany system GIS pozwala użytkownikom wyświetlać wizualnie bazy danych i analizować mapy. Możliwość sporządzania rysunków, tabel, wykresów sprawia, że mapy skutecznie wspomagają inżynierów PMS i ułatwiają komunikację się z zainteresowanymi stronami.

Keywords: GIS; Database; Maintenance; Rehabilitation; Road Network; Transport Planning.

1. INTRODUCTION

The Ministry of Foreign Affairs of the Slovak Republic regularly provides an official development assistance of the Slovak Republic, known as Slovak Aid Programme. The programme is dedicated to the implementation of assistance of the Slovak Republic

to the developing countries. In 2011 experts from the Faculty of Civil Engineering (FCE) at the University of Žilina finished their two years developing project “The Quality Roads and Bridges – The Infrastructure Connecting People”, funded by the Slovak Aid Programme and implemented in Ulaanbaatar,

Mongolian capitol, with close cooperation with the Ulaanbaatar city municipality. The main aim of the project was to develop an effective strategy for road network infrastructure management, reconstruction and maintenance. Slovak experts also elaborated methodology for crisis management and reduction of traffic congestions. In the first phase of the project FCE performed a complex analysis of road infrastructure in Ulaanbaatar and its traffic load. Slovak experts also provided training for the municipality road transport department staff. Later, employees of the municipality visited Slovakia with the aim of becoming familiar with Slovak system of road management, maintenance and reconstruction, and with road infrastructure planning in the context of urban planning. Employees were also trained to use newly developed GIS application and road database, its updating and maintenance. Project was finished by the final seminar. Mongolian partners received all projects outputs as follows:

- methodology for diagnostics of road surface parameters including recommendations for suitable test equipment and data used in road management – new Pavement Management System;
- radar based equipment Sierzega SR 4 – small and compact traffic counter and classifier;
- scheme for crisis management;
- GIS application of road network in Ulaanbaatar together with the scheme of road database;
- study of space aspects of road network development;
- and methodology for environmental impact assessment.

This paper describes particularly a development of GIS application for road network in Ulaanbaatar together with the creation of the road database.

2. LOCAL CONDITIONS

Ulaanbaatar is the capital with population of around 1,200,000 and also the largest city in Mongolia. Located in the northern part of the country, high above sea level, it ranks among the coldest capital cities in the world. Ulaanbaatar is the cultural, industrial, and financial heart of the country, and a hub connecting the Trans-Siberian Railway with the Chinese rail system. Due to the transformation of the country from communism to democracy in 1990, there have also been many substantial changes in a social life. About 40 percent of total population has moved into the capital city of Ulaanbaatar in the last

years. As a result of migration to Ulaanbaatar city, rapid growth of population has occurred and settle zones of ger areas (ger – yurt is traditional way of housing) have increased tremendously. Although Mongolia has vast natural lands and a traditional nomadic culture, its population is now mainly concentrated in the capital [1]. It has become a thriving urban centre in one of the most remote locations in the world. Ulaanbaatar is connected by roads to most of the major towns in Mongolia, but most roads in Mongolia are unpaved and unmarked. The main objective of domestic road network is to provide a connectivity between aimag centres (the first-level administrative subdivisions) and Ulaanbaatar, and between aimag centres and their surrounding region. To achieve this, Mongolia has a state road network of just over 11,200 km, of which only about 1,500 km are paved, 1,440 km has a gravel surface and 1,346 km has an improved earth surface. Over 6,900 km is earth tracks. On the state road network there are 364 bridges with a total length of just over 13,500 meters (an average length of 37 meters). But of these, 178 are of wooden construction and account for about 20 percent of the total length. [2].

Even within the capitol city, not all roads are paved and some of the ones that are paved are not in good condition. The capital has 418.2 km of roads, of which only 76.5 km are paved, the remaining being mostly earth tracks within ger districts. Of the 50 bridges in Ulaanbaatar, almost 90 percent are of concrete construction. The paved road network has remained largely unchanged in length for two decades. During this time the vehicle fleet has more than doubled. There are 450 km of sidewalks and 20,360 m² of designated parking areas in the city. At an average of 10 m² per parking place this gives only just over 2,000 parking spaces for the estimated 10,000 cars that enter the city each working day [2]. The city roads are generally in a poor condition with extensive cracking, potholes and subsidence (Fig. 1). This condition results from many reasons, but mainly from substandard quality of the original design, construction with inadequate drainage, and subsequent lack of maintenance. Lack of annual maintenance results in a permanence of surface water, as there is a widespread loss of grilles covering drains, leading to blockage of the drains themselves. There is an inadequate capacity of the storm water drainage system to cope with even a normal rainfall. Lack of snow or ice clearing in winter and no system of sanding or gritting road surfaces leads to an ice formation that lasts for a long time and slows traffic and increases accidents.



Figure 1.
Bad road conditions with potholes

There are only 103 km of roads, mostly compacted earth, in the ger areas that have a population about 400,000. The roads are substandard, with narrow carriageways and lack of even basic maintenance (Fig. 2). Travelling on these roads by vehicles is difficult if not impossible, so public transport vehicles or other public service vehicles have difficulty entering the ger areas. Even pedestrians have difficulty walking on narrow streets, often surrounded by wooden fences on both sides and sometimes blocked at one end. Of the 210 road junctions in the city of Ulaanbaatar, only 48 have traffic lights [2]. The city is overloaded with traffic, especially in morning peak hours.

The political and social changes in the past years have also brought an increase of long distance inter-city transport movements, accompanied by an increase in a short-distance movement for both passengers and freight, mainly in urban area. The mobility problems (traffic congestion and parking difficulties, public transport inadequacy, difficulties for non-motorised transport, environmental impacts and energy consumption) now have greater complexity and there is a potential for disruptions if this complexity is not effectively managed. There are serious troubles with traffic flow fluency at all important junctions and main roads. The traffic flow fluency is affected also by very bad quality of road network from the operating capacity characteristics point of view. Therefore there was an urgent need for the adoption of a common urban road transport management system that would address the specific issues and problems Ulaanbaatar is facing.



Figure 2.
Earth roads in ger areas [3]

The municipality did not use any regular or methodical system for road network management and maintenance. The project provided the system for planning maintenance and reconstruction of road network including the methodology for analysis of the quality of road infrastructure. The important part of the system was GIS application. The prior function of GIS was to store data about road network and to provide tools for urban planning, traffic management, economic and environmental analysis.

Transportation professionals usually use GIS as an important tool in managing, planning, evaluating, and maintaining transportation systems. However, in such difficult conditions, the question that arose was, if it is possible to make appropriate use of GIS for transportation system in country where human, technical and financial resources are limited. During developing GIS application in Ulaanbaatar we found

out that GIS based application could be relatively powerful and ready for practical use. In some respects it can be the same as those in more developed countries, but it differs in terms of applicability in practice.

3. GIS APPLICATION AND ROAD DATABASE

3.1 Original background and conditions

Before the implementation of Slovak Aid project the municipality of Ulaanbaatar kept at disposal the GIS system based on ESRI ArcView 3.1. The road management application was done by means of software extension which connected MS ACCESS database with GIS application. This application should enable management graphical and attribute information about roads, bridges, events on roads, maintenance of objects, accidents, evaluation and classification of objects and communications, but many problems and limitations were found. The system did not work properly and database was not updated and used for a long time. Database and GIS application were separated and GIS software was installed only at one workstation. Data structure included only very general and limited entities. Road network data in original municipality database were unrelated to each other, duplicative, and inconsistent. It was difficult to understand the relationships between different pavement attributes and the street locations and networks because there was an inappropriate way of graphical network used for representation.

Geometric data were entered manually by editing in shape file and after that, it was necessary to complete MS Access form with new ID manually. The evaluation of road quality was taken from external sources without partial values of factors influencing the road quality and conditions. Moreover graphical data were adapted from cadastre records and road network and objects were represented by polygon layers (Fig. 3). This kind of representation is not suitable for most of transportation network problems. Because of that, it was necessary to extend existing data model and ensure compatibility with the National GIS system for state roads. We decided to develop new system of road network represented by graph structure. A graph in this context is a collection of nodes and edges that connect pairs of vertices. Each node and edge can contain attribute information about road sections and all objects and in this way describe different road characteristics. This kind of model can be used for many problems of transportation planning

and road network management and maintenance.

3.2. Local node system (LNS)

New developed system with graph structure supports the road network model in form of vector local node system with defined network topology. This is the common way of representation of lines structures in GIS. The original polygonal representation of road infrastructure as shown in an example in Fig. 3 was replaced.

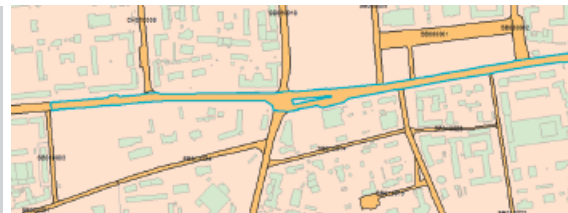


Figure 3. Original representation of junctions in form of one polygon

LNS have a linear reference form. The road network is represented by the compact system of edges and nodes with the topology relations among all components. The model is respecting political and administrative division of the city. This system enables untiring localization of all events that occurred in the network. When we localize the evaluated road section in LNS, we can obtain detailed information on all parameters. The example of localisation in LNS system for discrete event is presented in Fig. 4 [4].

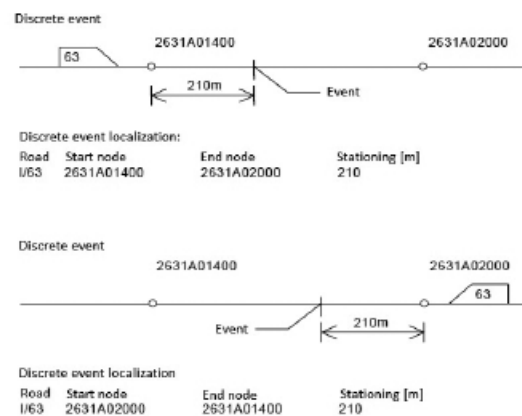


Figure 4. The principle of localization in LNS system [4]

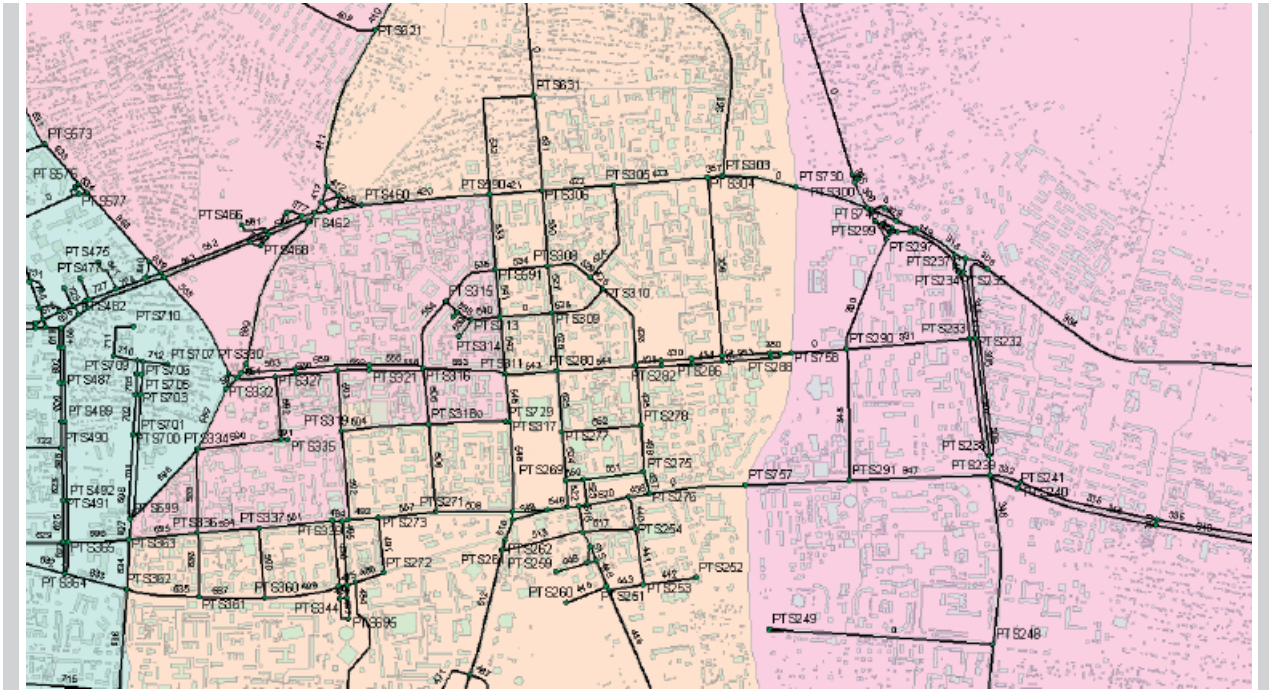


Figure 5.
The road network in LNS system

System enables to enter new elements of the road networks, edit or delete existing ones by working with nodes and edges (Fig. 5). It is possible to do that individually or more efficiently by batching. Different types of events representing deformation of road structure and different kinds of defects can be defined. Deformation has discrete or continuous values. Those functions are supported by appropriate mechanisms for data consistency control and for eventual correction of topology faults caused by editing new elements, or deleting and modifying existing ones. Attributes can be defined by their values or element type as follows:

- defined value
- continuous – real
- discrete value – integer
- type of topology element – point or line.

We defined the range of values for each parameter and restricted definition of attributes according to user hierarchy. The system enables a report generation. Reports are in tabular or graphical form representing road infrastructure splitting in homogenous sections in accordance with defined attributes.

3.3. Database design

One of the major challenges in implementing any PMS, is the availability of coherent engineering and economic data. The initial data was received directly from the municipality. Because of the limits of original data and whole original database (DB) we prepared a new data model. When preparing conceptual schema we followed the concept of existing database, LNS system, and new Pavement Management System. The new database has to store information for LNS and all information needed for the management of roads and also ensure facile data transfer between original database and the new one. Once we determined the relationships and dependencies amongst the various pieces of information, we arranged data into a logical structure (Fig. 6). Database was created in MicroOLAP Database Designer for PostgreSQL, where it is possible to define relationships between tables and data attribute types. There are tables in database as follows:

- ROAD – table with information about road
- BEARING_CAPACITY – table with information about road bearing capacity
- ROAD_MATERIAL – table with information about material of road structure

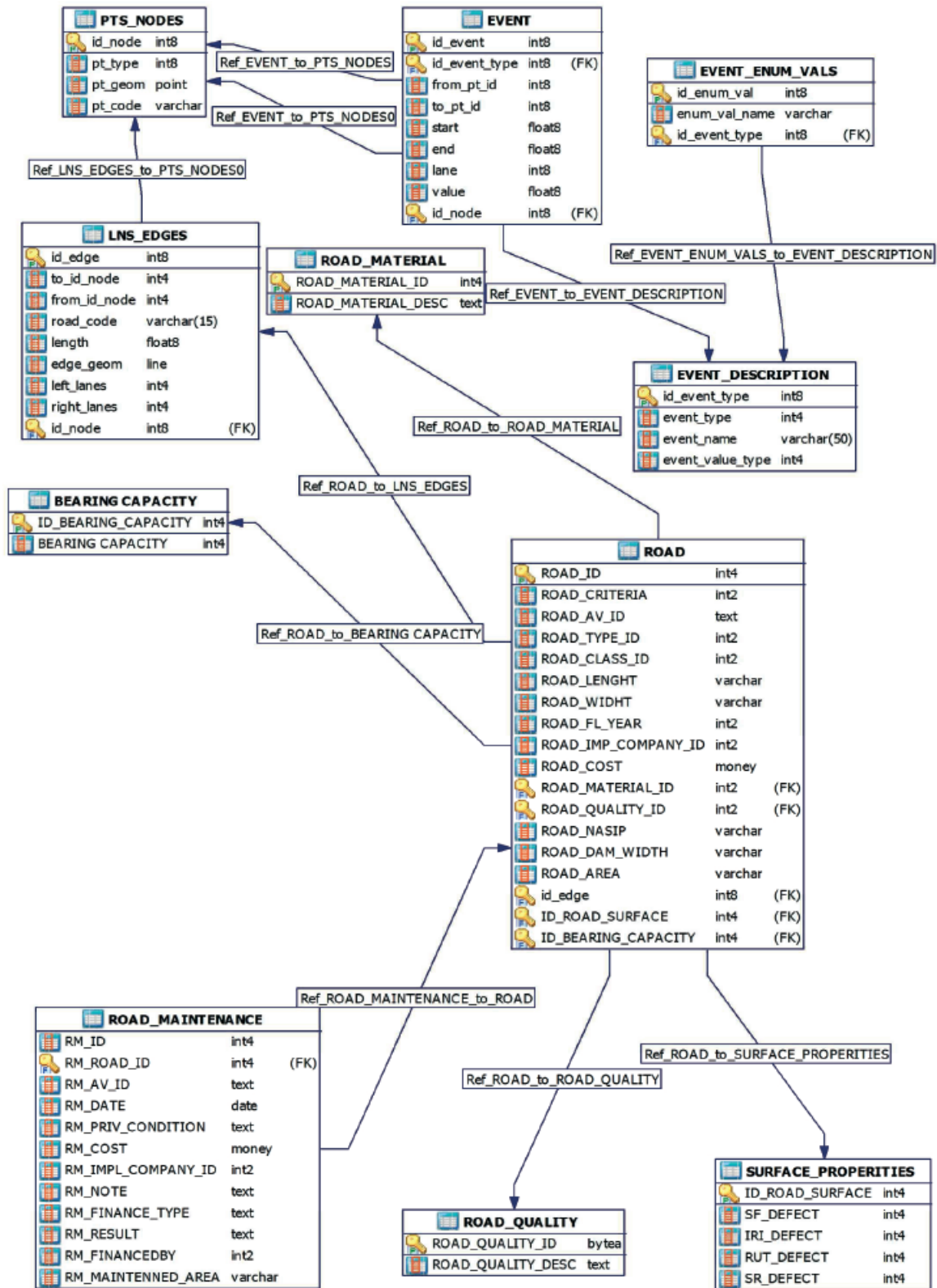


Figure 6. Database structure

- ROAD_QUALITY – table with information about road quality
- ROAD_MAINTENANCE – table with information about road maintenance
- LNS_EDGES – table to store information about edges, it means road sections
- PTS_NODES – table to store information about LNS nodes of edges
- EVENT – table to store information about events that occurred on roads
- EVENT_DESCRIPTION – table to store information about type of events
- EVENT_ENUM_VALS – table used in case, when the defined event has named value type. It is connecting text description e.g. “transverse roughness” with numerical identifier “transverse roughness” = 1
- SURFACE_PROPERTIES – table to store information about pavement parameters.

The final physical design of the database specified the physical configuration of the database on the storage media. This included specification of data elements, data types, indexing options and other parameters of data dictionary. We adapted the whole system according to requirements and needs of the final user – municipality. At Ulaanbaatar municipality the presentation layer is software ArcView 3.1. This software does not allow creating and managing DB supporting storage of information related to linear reference. In our case such information is information about events types with discrete and continuous parameters concerning the quality and condition of road structure, examined by field survey. We solved this problem by using extension PostGis 1.5 for PostgreSQL 8.4. This extension is an object-related system supporting GIS objects, which are stored in DB. DB was created by pgAdmin III and DB design by PostgreSQL.

The municipality provides central administration of new GIS application and database. Each system user has an access to actual and consistent data and information. The model of different access and task performance levels was defined together with its interaction. The system is implemented as an extension to already used ArcGis 3.1. The NLS system was suggested in the way of supporting connection with original database and new database. New system serves for storing, retrieving, analyzing, and reporting information to help with a pavement-related decision-making process. The system works on network level and project level. The primary purpose of the net-

work level management activities is to develop a priority program and schedule of rehabilitation, maintenance, or new pavement construction work within overall budgets. The new developed GIS system allows users to display visually the results of database queries and pavement management analyses on the map. Users can view network conditions and projected work programs. Integrated with graphs, tables, charts, etc., maps are very efficient in helping PMS engineers to communicate with politicians and other involved stakeholders.

3.4. Pavement Management System (PMS)

Regularly scheduled pavement condition inspection is one of the most important steps in implementing a comprehensive Pavement Management System. Such a system involves dividing the pavement network into logical segments, recording descriptive segment inventory data, and collecting pavement performance information related to these segments. This process provides the critical information needed for analysis to determine maintenance and rehabilitation requirements, project priorities, as well as conduct long-term planning. FCE developed a new methodology supporting decision-making process related to reconstruction of Ulaanbaatar road network. This methodology defines the principles of selection of road sections designed for rehabilitation. The main aim is to ensure the most cost effective solution for road reconstruction and maintenance. Diagnosis of road conditions is the base for decision making process enabling determination of the technical way of reconstruction and its costs. PMS requires different kinds of input data as follows:

- traffic intensity – measure of the average occupancy of a road during a specified period of time
- road structure details
- actual state of road parameters
- data for economical assessment.

The required input parameters for PMS are:

- 1) surface properties
 - surface defects
 - longitudinal unevenness
 - ruts – transversal unevenness
 - skid resistance
- 2) pavement bearing capacity.

Correctly identifying pavement failures and their causes are important for proposal of suitable reconstruction technology. FCE identified specific distress-

es which used to occur in the city. When recording pavement failures it is important to define the start and the end of failure and evaluate the degree of damage. The result is the calculated defect index. Developed PMS provides a numerical rating for the condition of road segments within the road network, where 5 is the worst possible condition and 1 is the best. The priorities for road rehabilitation take into consideration index values. Some of data are already available in database; others have to be measured in field.

4. CONCLUSIONS

Extensive work has been realized on the development of quantitative models in road transport research community to help road agencies make good decisions and planning of their maintenance actions. However, these models have to be adapted to each country conditions, especially in developing countries, where service levels and standards are lower and user's expectations and demands do not make visible some of the important trade-offs those road administrators of countries with more developed networks face. The analysis of the quality of road infrastructure in Ulaanbaatar is connected with the new developed methodology of Pavement Management System, including economical aspects of rehabilitation works implementation. Realised project will substantially help to overcome traffic problems in the city. Anyhow, it has to be connected with the complex analysis of the network traffic load as an important input parameter for pavement management system. The survey of the traffic intensity on main roads in the city, proposals for traffic reorganisations and assistance in avoiding congestion by planning alternative routes during reconstructions will also be very important in future. Project results were applied in the GIS system, where together with the urban planning elements will create the complex analytic tool used for effective management of road infrastructure in Ulaanbaatar. With the advent of inexpensive and easy to use GIS software, pavement management can go visual. Municipality can use GIS also to show areas repaired in previous years and see if the pavement management program's predictions were correct.

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