An overview road data collection, visualization, and analysis from the perspective of developing countries

V V Silyanov¹, J I Sodikov², R Kiran³ and A I Sadikov²

¹Moscow Automobile and Road State Technical University (MADI), 64, Leningradsky ave., Moscow, 125319, Russia
²Tashkent Highway Engineering Institute, 20 Amir Timur street, Tashkent, Uzbekistan
³Lonrix Limited, Unit 1.48 Tawn Place, Pukete, Hamilton, New Zealand

E-mail: osmijam@gmail.com

Abstract. Road data collection went through dramatic changes over the course of technology enhancement. It started with simple paper sketches of pavement distresses, then manual and automatic road data collection, current trends are mobile phone-based road data collection and in near future connected/autonomous vehicles based road data collection will dominate. The evolution of road data collection methods shows how technology is shaping the way how data is collected, stored and analyzed. Even though the technology is rapidly progressing, most of the developing countries are still practicing manual (visual) road data collection practices. The paper overviews the advantages and disadvantages each approach describes data quantity requirements proposes an approach for road asset management systems in developing countries. It also highlights how to visualize road data by utilization of open-source GIS software and briefly overviews turnkey solutions for road asset management.

1. Introduction

It’s a well-known fact that roads are blood vessels of an economy which carry loads and passengers across short or long distances safe and quick. To keep roads safe and in good condition, highway engineers have to know what is current road condition which requires the collection of road data. Various road data types can be collected such as road inventory data, road condition data, cost data, climate data, and historical data. It depends on the road agency’s policy on how much data would be efficient to make a proper decision. Some developed countries collect over 100 items related to road data. But in developing countries, there are challenges like lack of sophisticated computerized road survey vehicles, human capital to utilize hi-tech equipment and advanced pavement performance evaluation models, poor telecommunication systems, paper-based document exchange, and others. In the beginning, highway engineers collected road data by visually inspecting roads, some developing and third world countries still practicing paper-based road visual inspection. These include making sketches, taking notes and photography. Initial attempts to visually map pavement distress and its unification carried out by [1–2]. As road networks increased over time there was a need to collected road data by utilizing vehicles. Besides equipment based road data collection reduces rater’s error and increases safety. During this period when vehicle-based road data collection systems were started widely utilize, data collection system vendors offered automatic and manual data recording systems [3–4]. There were several papers related to the automated collection of various pavement distress. For instance, automatic rut depth data collection [5], automatic skid resistance data collection [6], and one
of the key pavement distresses such as pavement roughness collected manually and automatically [7–9]. Around the 90s and beginning 2000s road data collection system vendors started offering video recording data [10]. An increase in computing power led to incorporation simultaneous data collection of pavement distresses. Vendors like ARAN, DYNATEST, SIRANO, SCRIM, ROMDAS, and others started providing vehicles equipped with sensors, video logging, and GPS systems. ROMDAS utilized relatively inexpensive responsive type roughness measurement tool (bump integrator) with GPS and video logging specifically for developing countries [11]. Availability low-cost smartphones led to investigation of road data collection using smartphone acceleration sensor which behaves like bump integrator used for measuring road roughness [12–14].

2. Road data collection
It is a key element for pavement performance evaluation based on the quantity and quality of the data highway engineers who decide to minimize total cost of maintenance activities and works. Road data collection passes through several development stages such as in the beginning highway engineers used manual paper-based approach which is labor-intensive, low accuracy, requires skilled rater and limited data can be collected. The second stage of the development started in 1980s when vehicle-based road data collection systems gradually used by road agencies. Vehicle-based road data collection systems developed according to computer computing power and nowadays they have number of sensors for collecting roughness, rutting, skid resistance, odometer, GPS, video logging for road inventory and pavement crack detection. The cost of modern vehicle-based road data collection system depending on functionality may go up to 1 million US dollars. It requires highly skilled operator, data has high accuracy and detailed data. Smartphone road data collection initiated by using a built-in accelerometer to measure vehicle vibration which in turn can be converted into roughness index. Advantages this method of data collection is low cost of smartphone, no specific requirements for operator, acceptable accuracy and disadvantage is limited data can be collected. The future of road data collection is connected/autonomous vehicles equipped with high-resolution LIDAR cameras, GPS and numerous sensors. The advantages are zero cost of equipment, detailed data, high accuracy, and no operator are required. By utilizing deep learning algorithms data collected by connected vehicles can be automatically categorized and visualized on map which can be accessed by any highway engineer. Besides data continuously updated in real-time (Fig. 1). The evolution of road data collection methods shows how technology is shaping the way how data collected, stored and analyzed. Even though technology is rapidly progressing, most developing countries are still practicing manual (visual) road data collection practices. The reasons are lack of highly skilled operators, over-complicated road data collection systems, tons of pavement condition data, sophisticated pavement performance models. Therefore, there is a need for developing a simplified approach road asset management in developing countries.

![Figure 1. Road data collection evolution](image-url)
3. Road data visualization and analysis
In Uzbekistan, there is more than 43 000 km of public roads, in total, there is more than 183 000 km. A small fraction of network around 10 percent of the road network has pavement condition data which is collected by automated road data collection systems. The rest of the network partially surveyed by visual inspection in the spring or autumn seasons. These visual inspections are paper-based and used for quick fixes or follow the strategy “patch the pothole first”. To collect data across the whole network, a low-cost smartphone data collection has to be implemented. Availability acceleration sensor, GPS, photo and video recording in a smartphone make it a low cost and handy tool for measuring vehicle vibration in 3 axes (x,y,z) which in turn can be converted into roughness indices, GPS assists visualize various road attributes such as roughness index, photos and other road characteristics on map.

Two levels of analysis are proposed to optimally manage the road network in Uzbekistan. The first level is the network level where road agency manages the whole budget and entire road network. When financial resources are limited it’s impossible acquire all pavement condition data across the road network. At network level road agency needs to prioritize road works by regions. This can be achieved by weighting each region by suitable factors such as traffic volume, road condition, population or concentration industrial companies/agricultural centers. The other approach is to employ highway functional classification. Highway functional classification serves not only for identifying what function is playing certain road sections but also importance of that section. As one of the performance indicators AADT (Annual Average Daily Traffic) or VKMT (Vehicle Kilometers Traveled) plays significant role in budget spendings. Importance of each highway functional class: arterial, collector and local was defined by factors such as traffic safety, speed, riding quality and environment using analytical hierarchy process [15]. After prioritization regions by taking into account highway functional classification, the next step is to prioritization by road section in each region. Figure 2 shows pavement management system framework which sets relationship between data and budget at network and project-level analysis. At network level of analysis there is relatively limited data available because it’s practically impossible to collect data up-to-date all conditions and inventory especially in developing countries. Therefore, road agency has to develop a simplified tool to prioritize road works by regions. The analytical hierarchy process (AHP) can be used to prioritize road works at network level and project level. There is quite a large number of research papers dedicated on application of AHP in pavement management and optimization [16–25]. After prioritization by region, next step is to find road sections in each region that need to be repaired first. There are several approaches to optimize road repair works but one of the simple approaches is optimization using dynamic programming for detailed explanation reference [26].

![Figure 2. Simplified approach for road asset management systems in developing countries][1]
Developing countries are facing challenges not only in data collection but also in data storing and visualization. Moving from paper-based to digital technology requires extra technical skills and experience. Besides, there are two options open source and proprietary software. From developing countries' standpoint, open-source is most suitable because it’s free to use, distribute and customizable. But again it demands extra knowledge to customize road organization needs. Nevertheless, open-source GIS software QGIS provides quite a variety tools that can be used out of box to visualize road attributes (Fig. 3a and 3b).

There are turn-key solutions for road asset management. No asset management system can function in isolation. Successful implementation relies on three basic components – processes, people, and technology. Implementation requires that the agency must have a management mindset. Institutional policies and organization protocols must support a business process that can nurture the system. The technology adopted has to be effective and efficient. It must house the asset data and allow the required interrogation, analysis, and reporting. A suitable support and maintenance function is vital for sustainability. It is also important to recognize that no system is static. There will always be opportunities for refinements and improvements based on both the agency practice and technological progress. The framework acknowledges the importance of all three resource pillars noted above. As such, it provides a platform for the agency to implement management and auditing processes. At the same time – the flexibility of the framework, coupled with our highly energetic development team, is optimized for organizations with energetic asset management champions who have ideas of their own. Customized modules can easily be added at a fraction of the cost involved in configuring a more abstract commercial-off-the-shelf (COTS) system. JunoViewer is a framework for building modern, web-based asset management systems [28]. The JunoViewer platform is ideal for situations where clients have very specific, localized needs for reporting, workflow, and field inspection tools. It contains the following main modules and feature sets:

- Browser-based central web application and web-enabled data architecture.
- Store network asset inventory and condition data.
- Reporting and data analysis features.
- Centralized processing, storage, and streaming of digital content such as photos and videos.
- Develop and optimize budgets and Forward Work Plans (FWPs) for individual local governments.
- Analyze FWPs and budget requirements at the central and local government levels.
- Facilitate central management and auditing of FWPs.
- Perform graphical analysis and reporting of network condition and condition trends.
- Model and analyze future network conditions under different budget optimization scenarios.
- Facilitate GPS enabled offline field inspections with seamless sync-to-cloud server technology.
Facilitate offline smartphone apps for inventory and inspections of “off-pavement” assets.

A 100% customizable framework to meet all asset management requirements.

JunoViewer is built using modern web-based protocols supported by Microsoft technologies. The application is 100% browser-based and truly zero footprints. It requires no installation of software on the user’s computer or plugins in the browser – operations that would be challenging in a distributed government system. JunoViewer shines when it comes to making data trends visible so that it can drive informed decisions. Optimized for fast analysis of time series data, the framework can provide a wide array of graphs – either for individual segments, groups of segments, or for entire networks. Deterioration modeling is a core feature of the framework and facilitates budget and treatment optimization using established approaches such as the HDM models or later, more innovative approaches such as those based on Heuristics and Fuzzy Logic analysis techniques. The modeling architecture exists at two tiers. At the lower level is a suite of looping algorithms to optimize the allocation of funds based on optimal treatments. At the higher level is a modeling setup that the user can control. At this level, the user has full control over the model and can specify deterioration parameters and equations as well as the treatment selection algorithm. The day-to-day management of forwarding Works Plans (FWPs) is an integral part of the framework. An innovative Forecast View allows network managers and central planners to quickly see where and what work is planned. The FWP Summary view can be used to quickly see a summary of future costs and forecasted network conditions. JunoViewer makes it easy for you to create and store inventories and condition data for any asset type. Once an asset class and its attributes have been defined, the table structures are automatically created. The video analysis views enable the user to view their network video, paired with a number of other features, such as a map and strip map. Google StreetView is enabled on the map so the user can interrogate a specific location further in detail. In addition, scatter plot and trend graphs are available (fig. 4).

In conclusion, road agencies depending on long-term strategies, available financial resources, and human capital establish what type of data collection system is suitable for them, what data analysis and visualization tools fit company needs, what optimization method is the best option to succeed in minimization total cost. All these questions need to be answered individually but the key is to utilize available low-cost technologies such as the smartphone data collection method which indeed provides adequate accuracy at the minimal data collection cost. Smartphone acceleration sensors, GPS, photo, and video capturing capabilities make them attractive low-cost alternatives in comparison high cost and sophisticated automatic vehicle-based road data collection systems.
Figure 4. JunoViewer video analysis screenshot

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