

Preliminary Study on the Long-Term Pavement Performance (LTPP) Program under the Big Data Concept

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Abstract:

Big data is a collection of large and complex data sets that it becomes difficult to manipulate using common database management tools. This study explores the relationships among six subjects (climate, traffic volume, distress, friction, longitudinal profile, transverse profile) related to asphalt pavement performance using the largest pavement performance database (LTPP InfoPave) in the LTPP program. The data in LTPP InfoPave conforms to the natures (volume, velocity, variety, value, veracity) of big data. The SPS-3 experiment in the LTPP program is selected to conduct the correlation analyses. The correlation coefficient between average block cracking area and average raveling area is as high as 0.85. The correlation coefficient between average MRI and average block cracking area and average raveling area are 0.59 and 0.64, respectively. The finding shows that the smoothness has relatively lower relation to the surface distress, which is consistent with previous studies. This study serves as a reference for an application of big data to understand the pavement performance in depth. Engineers can keep exploring the LTPP program under the big data concept to earn more knowledge of pavement performance.

Keywords: Big data, pavement, pavement performance, pavement management system, long-term pavement performance program.

1. INTRODUCTION

“Big Data” refers to data sets that are large and complex they are not easily handled using the common database tools. These challenges are characterized by the five “V’s” - volume, velocity, variety, value, and veracity (Manyika et al., 2011; Hu et al., 2014). More data are inclined to more accuracy. More accurate analyses may lead to more confident decision making. And better decisions mean greater operational efficiencies, cost reductions and reduced risk. Big data launch unprecedented opportunities to significantly improve the effectiveness of decision-making with reduced cost by the large amount of data and information increasingly available in the civil engineering domain to generate useful knowledge for improved decision-making. With recent rapid advance in wireless techniques and equipment utilized in the civil engineering domain, the term “big data” which emphasizes volume (kilobyte, megabyte, gigabyte, terabyte, petabyte, exabyte, zettabyte, yottabyte), velocity (real-time, near real-time, periodic, stationary, non-stationary), variety (time-series, spatial, images), value (cost), and veracity (incomplete, subjective, objective, inconsistent) emerges and becomes very popular due to its high impact on engineering analyses and services (Attoh-Okine, 2014).

Poor materials, construction procedures, and quality of maintenance and rehabilitation activities can significantly reduce the lifespan of a pavement. Most deterioration of a pavement results from two general causes: (1) environmental causes such as aging and weathering and (2) structural causes attributable to external forces such as repeated traffic loadings and manmade damage. It is important to differentiate between the two causes to implement timely, appropriate, and cost-effective maintenance and rehabilitation activities, strategies that can prolong a pavement’s lifespan (Chang et al., 2012). Pavement management system (PMS) is largely a data driven process as one of the key elements is using data to support decision-making. With the advancement of sensor technologies, it become possible to collect the large-scale and detailed on-site pavement performance data using video logging, automated pavement distress survey, regular inspections, structural capacity monitoring, and other approaches. The PMS’s database representing inventory and historical records can rapidly explode. Simple operations such as capture, curation, storage, search, sharing, and analysis are challenging as pavement engineers’ ability to collect pavement performance data dramatically expands. This calls for a new concept to model this detailed level of big data for revealing new values for PMS. This study puts the efforts to review the applications of big data in civil engineering domain, especially pavement engineering. The long-term pavement performance (LTPP) program is used to explore the knowledge with regard to flexible (asphalt) pavement performance. The findings can serve as a reference for a successful application of big data to understand the

pavement performance in depth.

2. BACKGROUND REVIEWS

2.1 Big Data

The term “big data” refers to large, diverse, complex, longitudinal, and/or distributed data sets generated from instruments, sensors, Internet transactions, email, video, click streams, and/or all other digital sources available today and in the future (The Institute for Operations Research and the Management Sciences, 2016). Recently, big data concept has received notable attention for solving complex engineering problems. Among the engineering fields, big data is remarkably impacting the civil engineering domain. The operation, maintenance, and management of civil engineering systems are now undergoing noticeable transformation as a result of huge amount of information provided by emerging testing and monitoring systems. The key role of big data in this transformation is well-understood. Despite the significance of the big data concepts to process large-scale data, current information systems in civil engineering domain are still lacking in successful implementation of them. This study attempts to demonstrate the pavement performance analyses under the big data concept using the largest pavement performance database - LTPP InfoPave (Federal Highway Administration, 2016), as shown in Figure 1.

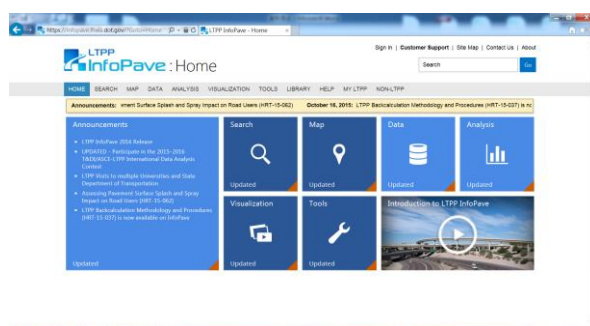


Figure 1. LTPP InfoPave (Federal Highway Administration, 2016)

2.2 Long-Term Pavement Performance (LTPP) Program

Strategic Highway Research Program (SHRP) was a 5-year research program that began in 1987 and cost \$150 million. The research areas under SHRP were asphalt, pavement performance, concrete and structures, and highway operations. One aspect of SHRP was the LTPP program. The LTPP program was designed as a 20-year study. The first five years of the program were completed under the funding and direction of SHRP, and, thereafter, the administration of the program was transferred to the Federal Highway Administration (FHWA) in 1992 (Federal Highway Administration Research and Technology, 2015). The objectives of the LTPP program are to: (1) evaluate existing design methods; (2) develop improved design methods and strategies for the rehabilitation of existing pavements; (3) develop improved design equations for new and reconstructed pavements; (4) determine the effects of loading, environment, material properties and variability, construction quality, and maintenance levels on pavement distress and performance; (5) determine the effects of specific design features on pavement performance; and (6) establish a national long-term pavement database to support SHRP objectives and future needs (Perera et al., 1998).

The data in the LTPP program are collected through cooperative efforts of highway agencies and the LTPP program organization. The collected data include information on seven modules: inventory, maintenance, monitoring (deflection, distress, and profile), rehabilitation, materials testing, traffic, and climatic (Smith et al., 2002). The data are subject to an extensive series of quality control checks before being provided to the public, and the data are organized in an information management system - LTPP InfoPave - that is the world's largest pavement performance database and is an important source of pavement performance information for the pavement community (Elkins et al., 2015). The FHWA/LTPP updates the database information on this website periodically (Federal Highway Administration, 2016).

3. PAVEMENT PERFORMANCE ANALYSES

The LTPP program includes two fundamental classes of studies and several smaller studies to investigate specific pavement related details that are critical to pavement performance. The fundamental classes of study are the General Pavement Study (GPS) and the Specific Pavement Studies (SPS). The GPS uses in-service pavement test sections in either their original design phase or in their first overlay phase. The SPS investigates the effect of

specific design features on pavement performance. The combined GPS and SPS programs consist of over 2,500 test sections located on in-service highways throughout United States and Canada. The LTPP program will monitor and collect pavement performance data on all active sites (Perera et al., 1998; Smith et al., 2002).

3.1 SPS-3 Experiment

Pavement performance information is important to maintenance and rehabilitation activities, as well as for overall planning and budgeting purposes (Shahin, 2005). Performance data gathered under well-controlled conditions can help quantify the cost-effectiveness of preventive maintenance treatments (Chang et al., 2005). The SPS in LTPP program is selected in this study to study the influences of preventive maintenance treatments on flexible pavement performance. The SHRP's Highway Operations research branch initiated Specific Pavement Study-3 (SPS-3). The SPS-3 experiment was designed to evaluate the cost-effectiveness of different preventive maintenance treatments on flexible pavements (Eltahan et al., 1999; Geoffroy, 1996; Smith et al., 1993). The SPS-3 experiment includes 454 sections located throughout 29 states in United States with diverse climate conditions. The slurry seal, crack seal, fog seal, and chip seal are the primary treatments in the SPS-3 experiment for long-term monitoring. For the SPS-3 experiment, the volume of the data collected from 1987 is considerably huge. The data are collected through real-time, periodic, and stationary approaches and updated in LTPP InfoPave relatively fast, which represents the nature of velocity. The data types include time-series, spatial, and images formats, which means the variety of the data is quite rich. The value of data collection is very high and cannot be measurable with money. Furthermore, although the data in LTPP InfoPave are subject to an extensive series of quality control checks before being provided to the public, the LTPP program still claims that the material contained on InfoPave website may have inaccuracies or typographical errors. This gives the nature of veracity. Based on the discussions, the analytical data used in this study are expected to be close enough to justify the term "big data".

3.2 Analytical Data

This study pays attention to the relationships among six subjects (climate, traffic volume, distress, friction, longitudinal profile, and transverse profile) related to flexible pavement performance. The specific tables are extracted and downloaded from the InfoPave website and tabulated as Table 1. The "()" in Table 1 mean the corresponding table names. The table descriptions are noted below Table 1.

Table 1. Analytical data

Subjects	Tables in LTPP program	Data volume (MB)	Sections	No. of records	No. of attributes
Climate	MERRA Yearly Temperature (MERRA_TEMP_YEAR) ⁽¹⁾	20.97	445	36,201	15
Traffic Volume	Trf Esal Computed (TRF_ESAL_COMPUTED) ⁽²⁾	1.02	445	2,952	5
Distress	AC Distress Survey Ratings (MON_DIS_AC_REV) ⁽³⁾	14.89	445	5,852	61
Friction	Friction Measurements (MON_FRICTION) ⁽⁴⁾	3.5	445	3,901	17
Longitudinal Profile	Longitudinal Profile Section Summary (MON_HSS_PROFILE_SECTION) ⁽⁵⁾	42.42	445	59,555	19
Transverse Profile	Transverse Profile Cross Slope (MON_T_PROF_CROSS_SLOPE) ⁽⁶⁾	12.65	445	17,090	8

Note:

(1) Air temperature 2 m above MERRA cell centroid elevation by year

(2) Annual kESALs for the year for those sections with monitored axle data

(3) Distress survey ratings from manual field inspections of pavements with AC surfaces

(4) Pavement surface friction measurements

(5) High Speed Survey section level profile computed parameters and statistics based on 150 mm interval data

(6) Elevation difference and distance between the inner and outer lane edges for transverse profile measurements

4. RESULTS AND DISCUSSION

The Tableau software (Tableau Software, 2015) is used to explore and visualize the analytical data as show in Figure 2. The table of "AC Distress Survey Ratings (table name is "MON_DIS_AC_REV")" is opened as an example at the right side of Figure 2. The Tableau is a data visualization software that lets analysts see and understand data in minutes. The MRI (mean roughness index) is calculated from the average of (IRI_LEFT_WHEEL_PATH) and (IRI_RIGHT_WHEEL_PATH) (Elkins et al., 2015). The average of MRI

(Avg. MRI), block cracking area (Avg. BLK_CRACK_A_M), and raveling area (Avg. RAVELING) are annually calculated from 1987 to 2005. Based on the line chart in Figure 3, the trends of average block cracking area and average raveling area are similar. The correlation coefficient between average block cracking area and average raveling area is as high as 0.85. The correlation coefficient between average MRI and average block cracking area and average raveling area are 0.59 and 0.64, respectively. The finding shows that the smoothness has relatively lower relation to surface distress. The result is consistent with previous studies. Moreover, the average block cracking area and average raveling area have high relation to each other. The correlation matrix is presented in Table 2.

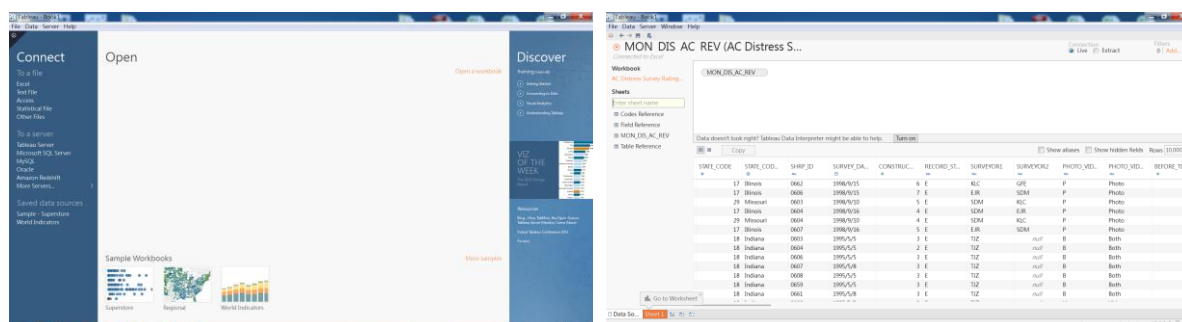


Figure 2. Tableau software (Tableau Software, 2015)

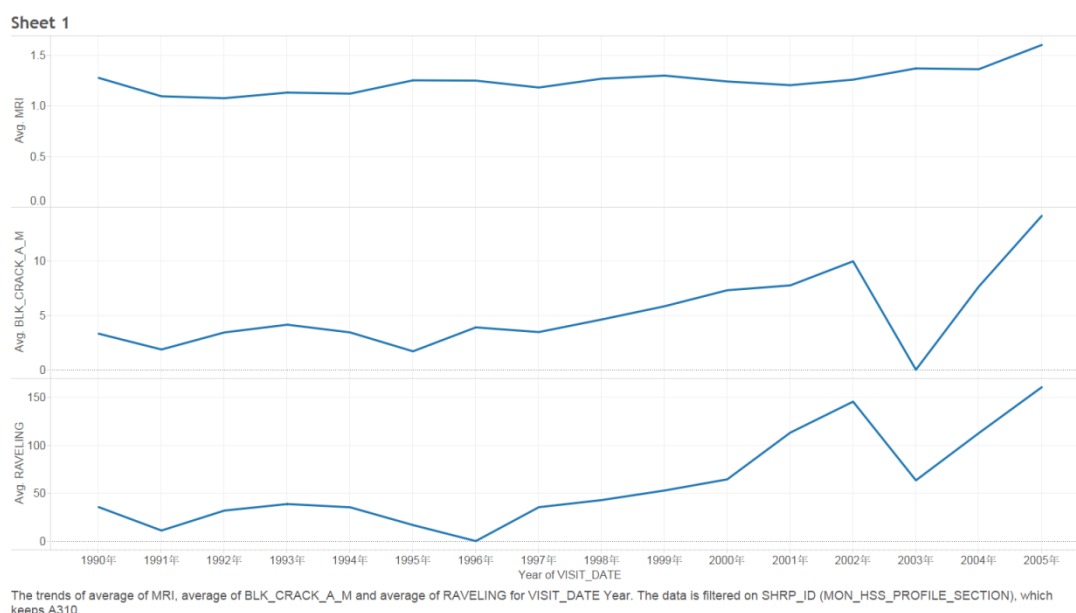


Figure 3. Analytical results

Table 2. Correlation matrix

	Avg. BLK_CRACK_A_M	Avg. MRI	Avg. RAVELING
Avg. BLK_CRACK_A_M	1		
Avg. MRI	0.58520898	1	
Avg. RAVELING	0.85647722	0.63638047	1

熊倉正志 et al. (2009) considered IRI as the criterion for pavement maintenance activities and resulted that the correlation coefficient between IRI and pavement maintenance index was 0.66. Furthermore, the correlation coefficient between IRI and cracking and rutting are 0.72, and 0.53, respectively. In addition, Park et al. (2007) studied the relation between smoothness and distress. The power regression model was used to analyze the data in LTPP program. The coefficient of determination between smoothness and distress is 0.59. The correlation between smoothness and distress are relatively low.

5. CONCLUSIONS

Big data describes the collection of complex and large data sets such that it is difficult to capture, process, store, search and analyze using conventional data base systems. This study explores the relationships among six subjects (climate, traffic volume, distress, friction, longitudinal profile, transverse profile) related to flexible pavement performance using the largest pavement performance database (LTPP InfoPave) in the LTPP program. The data in LTPP InfoPave conforms to the natures (volume, velocity, variety, value, veracity) of big data. The SPS-3 experiment is selected to conduct the correlation analyses. The average of MRI, block cracking area, and raveling area are annually calculated from 1987 to 2005. The correlation coefficient between average block cracking area and average raveling area is as high as 0.85. The correlation coefficient between average MRI and average block cracking area and average raveling area are 0.59 and 0.64, respectively. The finding shows that the smoothness has relatively lower relation to the surface distress, which is consistent with previous studies. Engineers can keep exploring the LTPP program under the big data concept to earn more knowledge of pavement performance.

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