Automated Data Collection System of Pavement Distresses: Development, Evaluation & Validation of Distress Types and Severities

Mubarak Al-Falahi 1, Ali Kassim 2

1 Municipal Roads & Infrastructure Department, Abu-Dhabi City Municipality, Abu-Dhabi, UAE
2 Carleton University, Department of Civil and Environmental Engineering, 1125 Colonel By Drive, Ottawa, ON K1S 5B6 Canada
malfalahi@gmail.com

ABSTRACT. This study presented an affordable and simpler technique that does not require complex technology and is suitable for middle size road networks. This technique involves taking pictures of various sections of the road network using cameras that can be mounted on public vehicles and transmitting taken images to a processing center. Each image is processed using image filtering techniques to produce an initial estimate of the PI. A total of 5,070 images and 507 sections (4 x 10 m per section) were taken and tested on a part of the Sheikh Maktoum Bin Rashid Highway E11 in Abu-Dhabi city (UAE) based on the quantity and clarity of the distresses. Six types of pavement distresses were tested; (1) longitudinal cracking, (2) alligator cracking, (3) block cracking, (4) pothole distress, (5) transverse cracking and (6) edge cracking. Three severity levels were considered: (1) low, (2) medium and (3) high. There were two distress measurement methods used to identify pavement distresses; semi-automated measurement (SAM) method and automated measurement (AM) method. In order to evaluate the accuracy of the AM method, two expert observers were used individually to extract the pavement distress by using the SAM method. The Cohen’s weighted Kappa used to determine the agreement between the two observers. The overall agreement result of the pavement distresses between the two observers was 98%, which is almost a perfect agreement. The overall agreement result of the pavement distresses between the two measurement methods was 89%, which is again an almost perfect agreement. In addition, the AM method validated by using R2 method and was found to be 0.93. The weighted mean speed of all distresses and standard deviation were found to be 58.56 km/h and 28.24 km/h respectively.

1. Introduction
Transportation systems are considered among the most critical and important components which contribute in a significant way to the national economy. For example, it accounts for nearly 11% of the USA Gross Domestic Product (GDP). Transportation systems provide links among nations, communities, businesses, industries, markets and consumers [1].

In order to ensure that constructed asphalt pavements will meet their long-term objectives, highway authorities must be able to schedule and implement timely maintenance. This requires the monitoring and detection of the pavement distresses utilizing reliable equipment to collect accurate and timely data.
In the past the detection and identification of pavement distress was carried out manually by trained technicians or expert inspectors who would collect the required information by walking along the road and record the pavement distresses using data forms or by driving along the road at speeds of 5-10 km/h using clipboard or special keyboard of PC acquisition device. The limitations of using this manual method are:

1. The quality of the pavement data is affected by the experience of the rater.
2. This method required time more than usual in order to collect and analyze data.
3. To check and correct any mistakes, it requires the return to the site again resulting in more time and costs.
4. It subjects the raters to safety hazards.
5. The manual methods cannot cover every sector of every road on a continuous basis.

The problem addressed in this work is to automate the collection and processing of data used to evaluate pavement conditions. The aim is to produce an automated system that continuously monitor the status of paved roads and use this data to establish an efficient rehabilitation and maintenance scheme. Such a system can save money and man power while at the same time it provides an updated view of the road conditions throughout the city at all times.

In general, the primary and main objective of this work is to develop an affordable simpler technique, which will not require complex technology, suitable for middle sized road networks, and economically viable [2]. More specifically, the objectives of the work can be achieved through the following tasks:

1. To develop an affordable automated data collection system to give an initial assessment of the status of pavement.
2. To develop an automated system that can classify the distress types, severities and densities within acceptable level of accuracy.
3. To build simple algorithms that can measure the distress in 2D.

In the next sections, this paper summarizes previous work, site description, data collection, analysis and results. A number of conclusions are listed at the end of this paper.

2. Previous Work

Windshield survey is defined as a manual survey to collect the pavement condition data by using a vehicle [3]. Vehicles can be driven along or on the shoulder of the road. The surveyor rates the pavement through the windshield of the vehicle. While this method covers more data in less time than a walking procedure, but the quality of the data is compromised [4]. The combination of walking and windshield surveys procedure according to [5] and [6] is considered a good procedure to inspect more pavement data and receive a greater percentage of the network.

There is a description of a semi-automated survey method which uses a moving vehicle to record pavement distress images by one or more than one camera mounted in front or back of the moving vehicle. Pavement images identify locations by GPS, then will be transferred to the hard drive in order to identify and classify the distress types, in the office, by trained persons [7].

In a study by [8] three systems were used for pavement distress data collection. The first system was developed by a Japanese consortium in the 1980s. This system consisted of a survey vehicle and a board data processing unit, in order to survey and measure surface cracking, surface deformation or rutting and longitudinal profile at night with an optimum resolution of 2048 x 2048 pixels at the speed of 10 km/h. The second system is the Pavement Condition Evaluation Services (PCES). This system contains a line scan camera at 512 pixels’ resolution. However, efforts were terminated due to the poor performance of the technologies at that time of the development [9]. The third system is the Swedish Pavue Pavement Data Acquisition System (PAVUE). The (PAVUE) system includes four cameras with proprietary lighting system and four S-VHS video cassette recorders [10].
A semi-automated system was conducted and produced by CGH engineering in Pennsylvania; USA is called Pavement Distress Analysis System (PADIAS). This system uses digitized images where a trained operator can analyze the distress data files and engineers can use and modify to meet their needs [11].

In contrast to the manual and semi-automated techniques. Automated techniques are equipped with a camera which can be used to perform pavement distress surveys without the interruption of normal traffic. Subsequently, software packages can automatically analyze pavement distress images and identify cracking patterns present on the pavement surface by type, severity and density [12]. Automated road analyzer (ARAN) vehicle is one of the most reliable automated systems in the world today. The unit has the capabilities to measure pavement conditions and distresses while travelling at reasonable speeds. The system collects data through two high resolution monochromatic cameras attached to the rear of a vehicle that scans pavement surfaces with strobe lights synchronized with the cameras [13].

There are many pavement management software packages developed by various pavement engineers and researchers that are capable of identifying pavement distresses, severities and density of distresses. Then the analysis of the pavement data is used to detect pavement distresses, severities and densities. Analyzed data can be stored in readable format or in GIS map forms that show the ranking of collected data according to certain manuals and guidelines. One of these software packages is Uni-analyze software that can analyze the collected pavement images. Uni-analyze software measures the pavement distress types, density and severity of cracks manually or automatically. Then, a color coded digital map presented by Uni-analyze, analyzes pavement condition data [14]. Another distress detection software is the Wisecrack software which is used by Furgo Inc. in automated road analyzer (ARAN) vehicle [13]. The Wisecrack displays detected cracks automatically (longitudinal, transverse, block and alligator cracks). Then the distress type, severity, density, and location of the distress can be produced and printed with available option of adjusting the architecture design to suit distress criteria. Then distresses can be evaluated from the collected images by using digital rating. The digital rating allows the rater to identify individual distresses and measure quantities.

After first paragraph, other paragraphs are indented as you can see in this paragraph. Please use the Vancouver numerical system where references are numbered sequentially throughout the text. The numbers occur within square brackets, like this [2], and one number can be used to designate several references. The reference list gives the references in numerical, not alphabetical, order. Please ensure that every reference cited in the text is also present in the reference list (and vice versa). Unpublished results and personal communications are not recommended in the reference list.

3. Data collection

3.1. Study Site and Equipment

For the purpose of measuring different types of distress, a road section was part of Sheikh Maktoum Bin Rashid Highway E11 as shown in ‘Figure 1’ was selected among several sites in Abu-Dhabi city based on the quantity and clarity of the distress. Sheikh Maktoum Bin Rashid Highway E11 is a divided four-lane two-way. The thickness of the pavement of this road is 60 mm of asphalt wearing course; 70 mm of asphalt base course; 300 mm of granular sub-base course; and 300 mm of subgrade. Various pavement distresses can be seen as transverse cracks distress, longitudinal cracks distress, alligator cracks distress, pothole distress, edge cracks distress, and block crack distress. In this study, an automated measurement system was mounted (workstation) on a prototype vehicle. A picture of the automated measurement system is shown in ‘Figure 2’.

Data collection was performed on April for 7 days in 2014 and covered three different time periods in one day. Each time period is two hours long. The first time period is between 8:00 AM and 10:00 AM. The second time period is between 1:00 PM and 3:00 PM. While the third time period is
between 8:00 PM and 10:00 PM. The total road section surveyed and the total photos captured were 507 sections and 5070 photos respectively.

In choosing a camera suitable for the objectives of this study it was important to define the image properties. The most common width of Abu-Dhabi standard lane is a 3.75 meter. In order to ensure covering the standard lane width of 3.75 meter, a 4-meter width was selected. Since two cameras to cover the lane were used, each camera should have a beam-width that covers two meters on the ground. It was also decided that the basic ground segment covered in one measurement is 4 x 10 meters. The 10-meter length is a reasonable compromise between very short and very long segments. Since the cameras will be mounted on the back of a vehicle or a bus at fairly low height above ground, a 4x10 image cannot be produced using a single shot. Therefore, it was decided to choose cameras that can take sequence of images while the vehicle is travelling at certain speed and then stitch these images together to produce the required image. A third consideration is the resolution and shutter speed of the cameras. The system is being designed such that images will be snapped while the vehicle is travelling at a speed ranging from 20 to 100 km/hr. This requires that each image of the sequence of images be snapped with very fast strong exposure before the vehicle displacement due to its motion affect the quality of the image pixels.

Illumination lights were added to the entire system with the two cameras in order to improve illumination of the sections during survey. A Global Positioning System (GPS) was used in order to determine the coordinate’s location of the section that was captured by the cameras. The GPS will provide a reference number and coordinates to each captured photo. A regular PC was used and equipped with a WIFI card used to establish connection with a central office. The captured images are passed to the Digital Signal Processing software (written in C++) [15], to process each image and extract the required road quality parameters. The wireless link is set up using a hand-held smart phone that offers a “personal hot spot”. The smart phone is connected to the Internet using 3G/LTE facilities provided by a service provider. Then the smart phone functions as a wireless router inside the vehicle and allows the PC to connect to the Internet. All processed data and images were transferred to a central processing location through this arrangement. The distance measurement instrument (DMI) is an accurate and reliable device which measures the distance and the speed. It also tracks GPS information on second by second basis. The DMI provides pulse every tire revolution and this pulse train is processed to trigger both cameras to take the picture and at the same time pick the reading from the GPS. The speed sensor is installed at the wheel and it is connected to the dashboard console unit.

3.2. Height camera calibration

Several trials were made in order to select an appropriate camera position that can cover road section of interest without including a useless data. The height of the two cameras was adjusted in order to avoid any interference in captured photos and covered the entire width. ‘Figure 3’ shows a schematic diagram that illustrates the different tried camera position and selected one.
Figure 1. Sheikh Maktoum Bin Rashid Highway E11.

Figure 2. Automated data collection vehicle.
3.3. GPS calibration
In order to calibrate the GPS, two different points in the same road section were selected. The coordinates of these points were checked by the coordinates that taken by another GPS. Then the distance between these points were calculated. If the difference between the distances more than the acceptable range of the GPS, the GPS will be restored and re-setup again.

3.4. Automatic scanning
The scanning is fully automated and the operator sends a command to the system to start scanning, storing and processing the road section. The DMI starts generating pulses every wheel revolution. This train of pulses along with the vehicle speed is processed to generate pulses that trigger the scanning. Each pulse causes the two cameras to scan and internally process one segment. When the cameras fully process one segment it sends it to the PC through the data acquisition module. The GPS stamps the section file with location and the DMI stamps it with the recording time and the vehicle speed. The (4 x 10) segment image is delivered to the PC as two synchronized (2 x 10) images, one from each camera and they get stitched together by the signal processing software residing in the PC. Each of the (2 x 10) images is produced by the camera after several internal stitches. The camera can be setup to take a burst of images and combine them into one integrated image taking into account the speed of the vehicle. The timing and synchronization is automatically adjusted to produce the image.

3.5. Software development
There is several ways to collect and analyze the image process. The use of computer software program technique is an economic and accurate way to collect and analyze the image processing. The C++ computer software was developed and used to analyze the image of pavement and identify its level of distresses. The level of distress depends on a number of parameters including: distress types, severities, and densities. In addition the software integrates the results of the image process into the distress map of the city. ‘Figure 4’ shows a flow chart describing the steps of the developed automated algorithm.

3.6. Distress measurement
In addition to the automated measurement method investigated in this study, a semi-automated measurement method was also used in order to examine the accuracy and validity of the automated measurement method. Therefore, two evaluation methods were used in this study, and can be classified as: [i] semi-automated measurement method (SAM), and [ii] automated measurement (AM) method. The evaluation of the two measurement methods are described in the following subsections.
4. Evaluation of the Semi-Automated Measurement Method

The semi-automated measurement method was used to identify the types of distress of the road pavement. Photos were observed and analyzed to identify possible types of distress. This method is used as a benchmark to evaluate the accuracy of the automated method. Each photo was independently reviewed by two different reviewers in different sessions. All extracted data was categorized, saved in an excel file and included; (1) distress types, (2) distress severity and (3) the percentage of the distress area. Six distress types were observed in all sections at the area under study which consisted of: transverse cracking, longitudinal cracking, alligator cracking, pothole, edge cracking and block cracking types. Distress severity was classified into three levels: low, medium and high severity. The percentage of the distress area was defined as the percentage area of each distress type out of the road section area. The dimension of the road section area was 10 meters by 4 meters. The total number of the sections surveyed was 507 sections.

Figure 4. Flow Chart of the automated developed algorithm steps

5. Agreement by Pavement Distress Type and Severity

The statistical analysis of data is based on what is known as the Kappa Coefficient. The Kappa Coefficient ($k$) is used to evaluate the level of agreement between the results of the two reviewers. Kappa coefficient is defined as “a statistical measure of the inter-agreement or inter-annotator agreement”, and is calculated as follows:
\[ k = \frac{p_o - p_c}{1 - p_c} \]  

(1)

Where:

- \( k \): kappa coefficient.
- \( p_o \): observed proportion of agreement.
- \( p_c \): proportion of agreement expected by chance.

Depending on the \( k \) value between two sets of observations, different levels of agreement between any two sets of observation can be obtained [16].

The strategy that was used to identify any pavement distress from a photo is noted as either 1 "crack" or 0 "no crack" [17]. The severity of each pavement distress was estimated from the measurement results. There were three different levels of severity that were identified: [i] low severity, [ii] moderate severity, and [iii] high severity. For example, when the mean width of the longitudinal crack is less or equal to 6 mm, the severity is defined as low severity, when the mean width of the crack is greater than 6 and less than 19 mm, the severity is defined as moderate severity, while when the mean width of the crack is greater than 19 mm, the severity is considered high severity. (table 1) shows the measure of agreement between the two reviewers.

**Table 1.** Kappa agreement strength of pavement distress types and crack severity levels between the two reviewers.

| Pavement Distress Type | Kappa "K" Value/ Agreement | Low     | Moderate | High     |
|------------------------|----------------------------|---------|----------|----------|
| Transverse             | 0.93                       | 0.95    | 0.85     | 0.79     |
|                        | Almost perfect agreement   | Almost perfect agreement | Almost perfect agreement | Substantial agreement |
| Longitudinal           | 0.94                       | 0.94    | 0.96     | 0.93     |
|                        | Almost perfect agreement   | Almost perfect agreement | Almost perfect agreement | Almost perfect agreement |
| Alligator              | 0.94                       | 0.96    | 0.95     | 0.96     |
|                        | Almost perfect agreement   | Almost perfect agreement | Almost perfect agreement | Almost perfect agreement |
| Pothole                | 0.92                       | 0.92    | 0.89     | Not applicable* |
|                        | Almost perfect agreement   | Almost perfect agreement | Almost perfect agreement | Not applicable* |
| Edge                   | 0.94                       | 0.95    | 0.91     | 0.94     |
|                        | Almost perfect agreement   | Almost perfect agreement | Almost perfect agreement | Almost perfect agreement |
| Block                  | 0.94                       | 0.96    | 0.95     | 0.90     |
|                        | Almost perfect agreement   | Almost perfect agreement | Almost perfect agreement | Almost perfect agreement |

No severity noticed

As shown in (table 1), the Kappa results showed that the agreement between the two reviewers was excellent and close to being a perfect agreement for all pavement distress types. Also, for the pavement
severity levels the results shows that the agreement between the two reviewers was excellent for all reported pavement distress types.

6. Evaluation of the Automated Measurement Method
The results of the analysis of the pavement distresses using the AM method were compared to the SAM method results for the two scenarios, pavement distress types and severity levels. Kappa coefficient \( (k) \) was used to evaluate the level of agreement between the two pavement distress measurement methods. (table 2) shows the agreement results of pavement distress types and severity levels as obtained by comparing the results of the SAM versus AM methods.

| Pavement Distress Type | Kappa "K" Value/ Agreement By Type | By Severity |
|------------------------|-----------------------------------|------------|
|                        | Low | Moderate | High |
| Transverse             | 0.65 Substantial agreement | 0.75 Substantial agreement | 0.75 Substantial agreement |
| Longitudinal           | 0.81 Almost perfect agreement | 0.71 Substantial agreement | 0.77 Substantial agreement |
|                        |     |          | 0.54 Moderate agreement |
| Alligator              | 0.87 Almost perfect agreement | 0.74 Substantial agreement | 0.85 Almost perfect agreement |
|                        |     |          | 0.77 Substantial agreement |
| Pothole                | 0.79 Substantial agreement | 0.88 Almost perfect agreement | Not Applicable* |
| Edge                   | 0.79 Substantial agreement | 0.87 Almost perfect agreement | 0.76 Substantial agreement |
|                        |     |          | 0.73 |
| Block                  | 0.85 Almost perfect agreement | 0.68 Substantial agreement | 0.81 Almost perfect agreement |
|                        |     |          | 0.78 Substantial agreement |

*No severity noticed

As shown in (table 2), the Kappa result indicates that the majority agreement between the SAM and AM methods was found to be substantial agreement for each pavement distress at the three levels of the pavement severity. Also there was no severity noticed at the high severity level when the pavement distress type was identified as pothole.

7. Validation of AM Method
In order to validate AM method, the coefficient of determination, R2, was calculated. The R2 was found between the individual pavement distress measurement methods, which are the estimated of the pavement distresses for the 5070 reviewed captured photos, using SAM and AM methods. The R2 was found to be 0.93 which indicate that there was a very good fit relationship between the two methods. The difference in counting cracks on overall sections between the semi-automated and automated measurement methods was calculated. If the difference is zero then the records agree,
otherwise there could be a difference ranging from -1 to +10. ‘Figure 5’ shows the count of the difference divided by 507 vs. the numerical value of the difference. The correlation coefficient, R, was found to be positive correlation and was equal to be 0.96.

![Figure 5](image)

**Figure 5.** Correlation between semi-automated and automated measurement methods

8. Analysis and Results

‘Figure 6’ provides frequency distributions of pavement distress types of the AM method. As shown in these figures, the majority of the pavement distresses were longitudinal and alligator cracking.

![Figure 6](image)

**Figure 6.** Pavement distress types distribution
‘Figure 7’ illustrate the effect of the time period during the process of capturing photos during the day. As shown from the figure, pavement distresses were very clear in the morning period. Therefore, the diagnosis of the pavement distress from the captured photos at the mooring was very clear, although the survey of the road section was the same during a different time period. Specifically, morning measurements provided higher percentage of cracks which mean that the lighting condition was better to clearly see and identify pavement distresses.

In order to make the automated measurement method more efficient, five different speed photo captures were used to survey the whole road section while capturing pavement distress photos. ‘Figure 8’ shows the relationship between the percentages of the pavements distress types related to each speed photo captures. As shown in Figure 8, the trend (distress rate) of the distress decreases while vehicle speed increases for Traverse, Longitudinal, Edge and Block distresses. While the trend (distress rate) of both Alligator and Pothole distresses are increased when the vehicle speed increases. It is expected that as the vehicle speed increases, other types of distresses are considered to be part of Alligator and Pothole. ‘Figure 9’ shows the weighted average speed photo captures, which was calculated by weighing every reported speed by the sample size. The weighted mean speed and standard deviation were 58.56 km/h and 28.24 km/h respectively.

9. Summary and Discussion
This paper examines an automated method to continuously monitor the road status and rank the priorities of required maintenance. The new development measurement method consisting of two cameras, GPS and Distance Measuring Instrument (DMI) as well as a board processor. The system can be mounted on public vehicle such as public transportation buses or municipality service vehicles. As those vehicles roam around doing their respective functions, they also take snapshots of the pavement, process them on board and transmit the reports to a control center. Each snapshot is stamped by location and time.

A two km road section in Abu Dhabi, UAE was used as a test bed. More than 5000 snapshots were recorded and processed at different times (morning, afternoon and evening) and at different speed (20, 40, 60, 80 and 100 km/h). Each file was processed automatically Automatic Measurement (AM) to determine the number and severity of pavement distresses. The distresses are cracks of 6 different types: longitudinal cracking, alligator cracking, block cracking, pothole distress, transverse cracking and edge cracking. Three severity distress levels were considered: low, medium and high.

The files were also processed manually by two independent observers. This manual inspection of the photo is called as Semi Automated Method (SAM). The statistical analysis was performed on the collected data as follow: First, the results of the SAM were studied by correlating the results reported by the two independent observers. The “Kappa” factor was used to test this correlation. The Kappa result was found to be 98% between the two different reviewers, which is almost perfect agreement. Also, the automated measurement method was validated using R2 method, which found to be 92.5%. In addition, the correlation coefficient, R, between the Semi-Automated and Automated measurement methods was found to be positive correlation and equal to 96.1%.
Figure 7. Pavement distresses distribution; a) in the morning, b) in the afternoon, and c) in the evening.
Figure 8. Percentages of pavement distress type related to each speed

Figure 9. The weighted average speed photo captures
10. Conclusions
The work and results presented in the paper support the following conclusions:

1. This work is presented a reliable and cost effective technique to collect comprehensive field data related to pavement distress and pavement condition.
2. The new developed system is innovative since it mobilizes public transit vehicles with the equipment of the new system. Thus, unlimited amount of data collection can be performed over the entire road network for most of the day and for seven days a week.
3. The new developed system is safer and less expensive than the other present systems and would allow images to be taken in various times of the day as well as with different speeds which provide several advantages over the ones that have to be operated either manually or with high speed vehicles.
4. Practically, the new developed measurement method can support large-scale data collection for investigating different pavement distresses.
5. It was found that the speed to capture more reliable and clear pavement data was 58 km/h. Since the maximum allowable speed of the buses at the surveyed city is 60 km/h, then the range flow within the maximum speed of public transit buses. In addition, the fact that the buses stop can provide a more reliable pictures at their stops and intersections.
6. Longitudinal and Alligator cracking were found to be the majority of the pavement distress types among the all different pavement distress types reported on the test sections of this research.

Based on the results and conclusions of this work, the following points require further research:
1. The presented technique can benefit from automated road user classification using 3D camera. This can be utilized to measure other distress types that cannot measure using the 2D cameras. Clearly, surface rutting and deformation will be ideal for the 3-D cameras.
2. Road map can be added to the presented technique in order to prioritize the pavement maintenance and rehabilitation projects

Acknowledgments
The authors would like to thank the Government of Abu Dhabi and the Abu-Dhabi Municipality for their assistance throughout this study.

References
[1] Washington, Simon P, Karlaftis, Matthew G and Mannering, Fred L. Statistical and Econometric Methods for Transportation Data Analysis. s.l. : Chapman and Hall/CRC, 2010.
[2] Shahin, M Y. Pavement Management for Airports, Roads and Parking lots. Newyork : Chapman and Hall, 2011.
[3] Flintsch, Grrardo and McGee, Kevin K. Quality Management of Pavement Condition Data Collection. Charlottesville, Virginia : Transportation Research Board, 2009.
[4] Windshield Surveys of Highway Condition: A Feasible Input to Pavement Management. Hartgen, David T and Shufon, John J. 938, 1984, Transportation Research Board, pp. 73-81.
[5] Rababaah, Haroun. Asphalt Pavement Crack Classification: A Comparative Study of Three AI Approaches: Multilayer Perceptron, Genetic Algorithms and Self-Organizing Maps. Indiana : Indiana University, May 2005.
[6] Hass, Ralph C, Hudson, W Ronald and Zaniewski, John P. Modern Pavement Management. Malabar,FL : Krieger Pub. Co, 1994.
[7] Walther, J A and Shahin, M Y. *Pavement Maintenance Management for Roads and Streets Using Paver System*. Champaign : US Army Corps of Engineers, 1990.

[8] *Designs and implementations of Automated Systems for Pavement Surface Distress Survey*. Wang, Kelvin C.P. 1, 2000, Journals of Infrastructure Systems, ASCE, Vol. 6, pp. 24-32.

[9] McGhee, Kenneth H. *NCHRP Synthesis of Highway Practice 334: Automated Pavement Distress Collection Techniques*. Washington, DC : National Cooperative Highway Research Program, Transportation Research Board, 2004.

[10] IMS Infrastructure Management Services. An Overview of the PAVUE Fully Automated Surface Distress Image Processing System. s.l. : IMS, 1996.

[11] CGH Pavement Engineering Inc. Distress Surveys. [Online] CGH Pavement Engineering Inc., 2002. [Cited: 12 13, 2012.] www.cgh-pavement.com.

[12] Epps, J A and Monismith, C L. *Equipment for Obtaining Pavement Condition and Traffic Loading Data*. Washington, DC : Transportation research Board, NCHRP Synthesis 126, 1986.

[13] Road Group Inc. Autmatic Road Analyzer System. [Online] Road Group Inc., 2002. [Cited: 2 3, 2013.] www.roadware.com.

[14] Dynatest Consulting Inc. Uni analyze. [Online] Dynatest Consulting Inc., 2011. [Cited: 3 1, 2013.] www.dynatest.com.

[15] Solter, Nicholes A and Kleper, Scott J. *Professional C++*. New Jersey : Wiley Publishing, Inc, 2005.

[16] *Understanding Interobserver Agreement: The Kappa Statistic*. Viera, Anthony J and Garrett, Joanne M. 5, 2005, Family Medicine, Vol. 37, pp. 360-363.

[17] *Assessing Variability of Surface Distress Surveys in Canadian Long-Term Pavement Performance Program*. Goodman, Stephen. 2001, Trasportaion Research Board, Vol. 1764, pp. 112-118.