

Implementation of Automated Network Level Crack Detection Processes in the State of Maryland

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ABSTRACT

The Maryland State Highway Administration (MDSHA) has collected cracking data on its roadways for use in its Pavement Management System (PMS) since 1984. Through much of this history the pavement cracking survey was performed yearly by teams of inspectors riding in vans. With the re-engineering of the Administration over the years, this process began to present serious resource and logistical problems. Over the past three years, the MDSHA Pavement Management Group has developed and implemented a state-of-the-art automated network level crack detection process that is showing promising results. This process is based upon the use of the ARAN data collection vehicle, Wisecrux (WX) crack detection software and an intensive quality control (QC) and quality assurance (QA) procedure. The data collection and data processing tasks are all performed in-house with MDSHA resources. This paper provides an overview of the processes developed and implemented by MDSHA to conduct these surveys. The paper also discusses challenges and lessons learned during the implementation process. Presentation of this information will allow others to gain insight into the strengths and weaknesses of adopting such a system and promote information sharing among pavement data collection organizations. Overall, it is concluded that automated network level crack detection is a viable and efficient tool. However, a strict QC/QA regime must be instituted in order to achieve consistent and repeatable results.

INTRODUCTION

MDSHA invests approximately \$100 million annually to maintain and preserve the State highway pavement network. The MDSHA pavement network includes just over 16,000 lane-miles of highway pavement distributed across seven engineering districts statewide. Three of the districts are located in rural areas, one in Western Maryland, a mountainous region, and two in the Eastern Shore of Maryland, a coastal region. The remaining four districts include a majority of the network mileage in urban or metropolitan areas around the cities of Washington, D.C., Baltimore, Annapolis and Frederick. Organizationally, all pavement management planning and pavement design efforts are conducted centrally within the Office of Materials and Technology (OMT) with funding and project selection approved through the Office of the Chief Engineer (1).

In order to use this funding wisely, MDSHA developed a state-of-the-art pavement management system (PMS). This system has been designed for, and driven by, the business processes established in MDSHA. The goal is to provide capabilities to monitor the health of pavement networks, forecast service conditions, anticipate maintenance needs, and determine optimum treatment plans that comply with established policies and adhere to engineering and economic constraints. As part of this effort, a number of analysis tools and data management components were developed. One of the essential components is a tool for modeling and predicting the pavement performance. The models are considered the main drivers behind all planning and forecasting tasks, and designing a reliable performance modeling tool is crucial to the overall effectiveness of the State's pavement management system (2). The PMS is conceptually structured as shown in Figure 1.

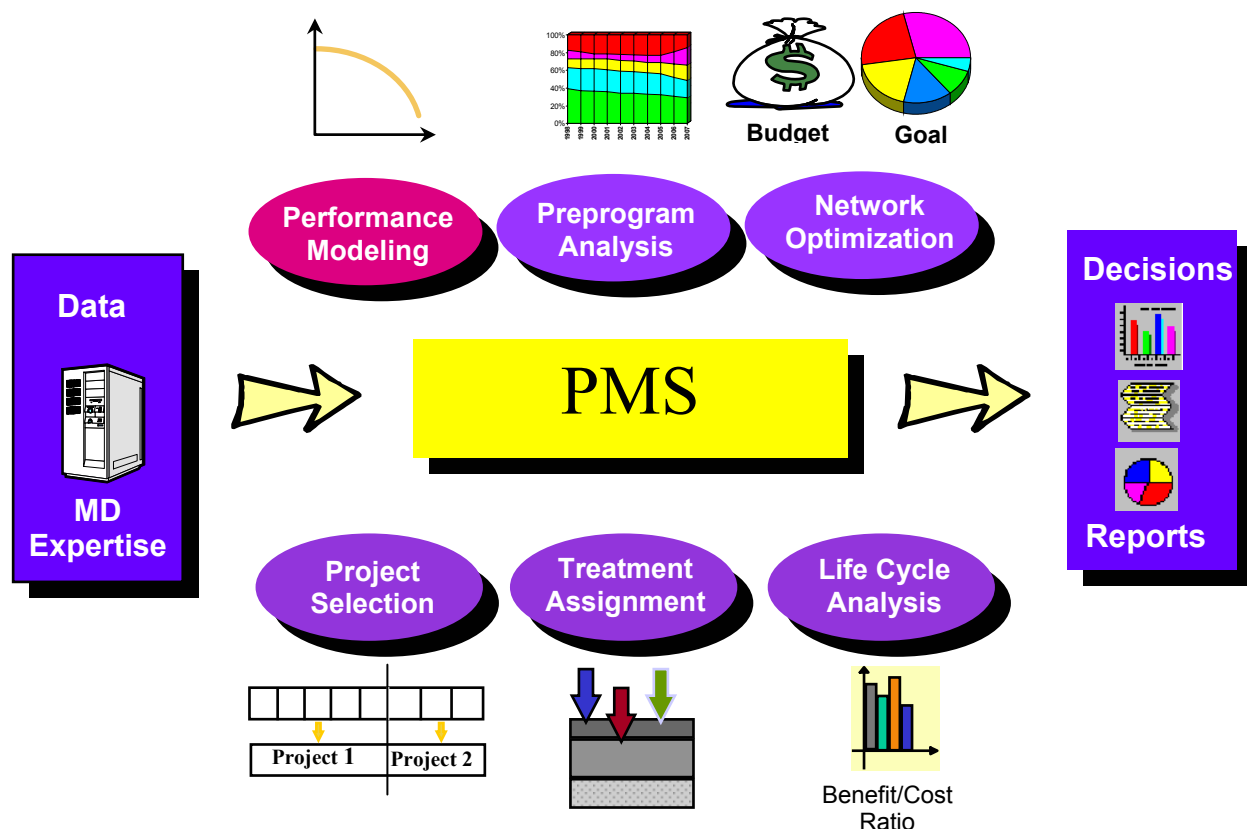


FIGURE 1 Conceptual diagram of MDSHA's PMS

To produce suitable pavement performance indicators, pavement cracking data must be an integral part of these models. MDSHA has obtained cracking data in the past by utilizing a team of experts traveling in a van to rate the pavements. As can be imagined, this was a tedious, labor-intensive process. In 1995, an Automated Road Analyzer, or ARAN, was purchased. This purchase enabled the State to capture pavement images and perform crack analysis on a network basis. After a period of experimentation and development, an efficient, accurate, and repeatable process evolved. This paper focuses on the procedures that resulted from this development period and intends to provide readers with some insight into the potential pitfalls and issues regarding these procedures. It is intended that this dissemination will allow others to reduce the learning curve during implementation of similar processes.

DATA COLLECTION PROCEDURES

MDSHA's ride, rut, and cracking pavement performance data are collected using an ARAN vehicle operated by State forces. The data collection season normally runs from spring through early fall. The entire network is surveyed every year. As a minimum, one lane in each direction is surveyed. Out of the total of 16,000 lane-miles, this results in approximately 10,000 lane-miles which are surveyed in a given data collection season (only one lane of multi-lane facilities is surveyed).

The ARAN vehicle is equipped with state-of-the-art equipment to collect information about Maryland's highway infrastructure. The combination of high resolution digital video, ultrasonic sensors, accelerometers, gyroscopes, Global Positioning Systems (GPS), and a distance measuring device are used to collect data at highway speeds. As it travels, it collects information on rutting and roughness, grade, and curve radius. It also collects right-of-way digital video. Digital photographs of the pavement view are taken by two rear-mounted, downward looking cameras.

In terms of pavement performance measurement, the ARAN produces a longitudinal profile of the roadway using lasers that measure the vehicle's height above the roadway and accelerometers monitor the vertical forces caused by surface deformities. This profile is used to calculate the International Roughness Index (IRI) and thus provides a measure of the riding comfort of the road. The profiling capabilities of MDSHA's ARAN exceed the specifications reserved for Class I profilers.

A "rut bar" comprised of 37 ultrasonic sensors is used to determine the amount and severity of rutting. These sensors measure the transverse profile of the roadway. Accurate rut depth measurements are valuable for identifying areas which are susceptible to hydroplaning due to road surface water ponding.

In addition, the digital pavement images are collected and stored on removable hard drives. These images are processed off-line at a workstation by State forces. The remainder of this paper documents the process used by MDSHA to turn these images into cracking data.

The data collection process has evolved over many years in the MDSHA and is now a mature and robust part of the business process used to collect pavement performance data. Many customers within and outside the State use this data and it is now integrated with the Geographic Information System (GIS). By pushing a button within the GIS, a full database of inventory, performance, and right-of-way data can be accessed. The use of digital right-of-way images has now been rolled-out statewide and as a result the Pavement Division has seen a large increase in the number and variety of customers who are utilizing this information.

DATA PROCESSING

The pavement view images (on removable hard drives) are brought into the office on a weekly basis by the ARAN crew. A log sheet of roads surveyed accompanies this submission. From there, a backup process is initiated to archive this important data. After proper archival, the network level evaluation consists of the following tasks:

1. Data Management
2. Pre-processing
3. Processing

4. Quality Control
5. Quality Assurance
6. Classification and Rating
7. Data Reduction

Each of these tasks is discussed herein.

Data Management

The paper log sheets delivered by the data collection team are transferred into a database maintained by the Pavement Division. This log serves as a critical piece of information to measure progress throughout the year. The table contains information such as route number, direction, mileposts, file name, and the data collection date. Basically, this serves as an inventory of data collection progress. Data are cross-checked with PMS inventory records to make sure appropriate road sections are being collected. In general, a road section is defined as a segment of a particular road within a county - for example, US 50 in Princes Georges county. Another tool, described in the data reduction portion of this paper, is used, along with this database, to monitor crack detection progress. This database is updated continuously as data are collected and processed.

Pre-Processing

Next, the appropriate data are loaded onto the WX processing computer from the archived tapes. This data consists of a control file, which contains all of the reference information, and a series of digital image files stored in “jpg” format. The control file is, of course, very important to this whole process – without it, no data could be processed. For a given road section, the construction history associated with this segment is reviewed to identify new overlays within the section. In general, overlays one or two years old are not processed for cracking. The cracking is assumed to be zero for these sections. This, of course, speeds processing and review time.

The WX program is then initiated and the appropriate data are loaded into the program. The operator then examines the images that were collected to make sure they are suitable for processing. This includes making sure that an image is present, lighting is even, and the image is clear. A series of adjustments are then undertaken within the software to make sure the crack detection parameters are acceptable for this segment. Default selections have been established to make this procedure more efficient. This is the most important part of the crack detection process and it involves a great deal of experience by the operator to perform well. The details of this process are not suitable for this paper but the manufacturer’s user’s guide and training ensure that operators are skilled to perform this task. As part of this process, the operator performs trial crack detection on a variety of stations within the road section. This is done to ensure that crack detection is occurring correctly. Parameter settings are sensitive to changes in pavement color and texture so, in the end, a compromise set of parameters that best apply to the entire section is usually chosen. It is also possible to choose separate crack detection parameters for individual sections within a pavement, but this option is not normally performed in MDSHA due to time and efficiency constraints. Identification of 80 percent or greater of all visible cracks is the benchmark used to determine if crack detection is adequate.

Processing

When the operator is satisfied that crack detection parameters are suitable, a “batch” (usually a series of roadways) is loaded and the crack detection process is initiated. At this point, WX goes into automatic mode and detects cracks at a rate of approximately 13 to 17 miles an hour (on a 700 MHz machine). This rate is dependent on processor speed, amount of cracking and many other factors. This process is usually conducted in the evening as there is no operator intervention. The amount of data that can be processed in an evening is a function of computer storage and memory capacity. At MDSHA, 60 or more miles are typically processed in an evening by one machine. Currently, three machines are used to process data overnight.

Quality Control

One of the most important aspects of the network level crack detection process is the use and strict adherence to QC procedures. QC of WX data processing is generally carried out by the individual who set-up and initiated processing. However, it may be carried out by anyone who is experienced in the WX pavement distress rating process. QC processes are initiated on processed sections as soon as possible after completion prior to commencing WX on new sections. This is necessary to prevent processing of large amounts of data without adequate QC.

The steps for performing QC are as follows:

1. Review of processing completeness,
2. Review of section level data,
3. Review of data management.

Review of Processing Completeness

QC personnel review the crack detection results to ensure that all files in the “batch” were processed. If this is acceptable, then the QC operator proceeds. If not, then the cause of the failure is investigated and the batch process is restarted to complete the evaluation.

Review of Section Level Data

The QC process is best learned by experience. After performing this process a number of times the operator can generally evaluate the success of the crack detection process by reviewing the crack summary graph generated by the WX program (there are certainly exceptions to this rule). The crack summary graph includes a display of the total quantity of cracking detected by station. If the batch has been set-up correctly, generally the operator can look for “spikes” in the crack summary graph. A crack summary graph that has many spikes is a warning sign that the evaluation may not have been conducted correctly. The operator then reviews pavement images with superimposed cracking to ensure that crack detection occurred correctly. This is generally performed in a random manner using the following intervals:

- Review one of every 10 stations for sections that are less than 3.0 miles long,
- Review one of every 20 stations for sections that are 3.0 to 10.0 miles long,
- Review one of every 30 stations for sections longer than 10.0 miles.

Stations are approximately 52 feet long. When reviewing crack detection results, the operator identifies stations with too much cracking detected, not enough cracking detected, and “phantom” (detected cracks that do not exist) cracks. The key goal is to achieve 80 percent crack recognition (a subjective measure). Please remember in this discussion that the focus is on network crack detection where a gross indication of crack performance is needed. If this was a project level evaluation, these criteria would be much more stringent.

Along with this review the operator checks the PMS database to determine when the last major action was performed. If a thin treatment was last applied 20 years ago, you would reasonably expect for the section to have a higher amount of cracking. Likewise, if the section had a medium overlay last year, you would expect minimal cracking.

In general, good pavement should have an average of less than 20 cracks detected, fair pavement usually has an average of 20-50 cracks and poor pavement has approximately 50-150 cracks present per station. Any station with greater than 150 cracks is usually (but not always) a concrete section. A section containing a concrete bridge deck usually has over 400 cracks present. These are very general numbers presented only to give the reader a feel for the amount of cracking detected by WX on various

pavements. As an aside, crack detection is only performed by MDSHA on asphalt pavements. Sections that contain concrete and bridge sections are filtered out of the dataset.

Review of Data Management

The last step in the QC process is to make sure that the data has been saved to the WX computer hard drive and the appropriate database is updated. At the conclusion of this process, the next batch can be initiated. Also, the QC operator places their name and the date QC'd as well as their subjective evaluation of the WX detection process in the data management spreadsheet to document QC has been completed. The subjective rating process consists of three levels, Good, Fair, and Poor based on percentage of stations processed, accuracy of crack detection, whether results were saved to a hard file and whether results were saved to the network. Any comments related to QC are entered as well.

As a guide to assist in this process, Table 1 is referenced. The lowest rating found is used to assign a QC rating. Therefore, if all criteria are "Good", except data has not been saved to the hard drive, then the overall evaluation would be "Poor."

TABLE 1 QA rating matrix

QC Procedure	Good	Fair	Poor
Stations Processed	100%		< 100%
Criteria 1: Cracking > 80%	> 90 % Stations	70-90% Stations	< 70% Stations
Saved to Hard Drive	Yes		No
Saved to Network	Yes		No

Quality Assurance

QA is performed to check that the QC process was conducted properly and is conducted on a weekly or bi-weekly basis. This process is conducted by a Quality Assurance Auditor (QAA) who is required to be an individual other than the person who ran the WX evaluation on a group of sections. QA is normally conducted on a weekly or bi-weekly basis. The QAA inspects the data management spreadsheet to document data that has been processed during the current week (or since the last QA audit). The auditor ensures that the spreadsheet has been fully completed and all information is correct.

Ten percent of data are selected for QA review. Therefore, if 100 files have been processed during a given week, the auditor will select ten for review. The QAD evaluates an equal number of files processed by different operators during the evaluation period. Also, any files that have comments that are out of the ordinary are inspected in their entirety.

To conduct the review, the auditor performs the QC process documented earlier on the selected file. The QAA determines a QC rating for the WX evaluation (good, fair, or poor). If any evaluations do not agree with the original QC evaluation rating, it is noted on the data management form.

If more than 2 discrepancies are noted within one data file, then 50% of the file is reviewed to see if there is a systemic problem with crack detection for this file. If more than 10% of the QA sample (the 50% selected for review) has discrepancies, then consideration is given to throw out all data and repeat the WX evaluation process. All discrepancies are discussed with the operator(s) and a consensus reached as to final evaluation rating. These ratings are very important during data reduction. The MDSHA Pavement Management Assistant Division Chief has final authority over any technical disputes or differences in opinion regarding this process.

Finally, the QAA ensures that all data have been backed up and archived as per instructions. The following is a summary of those requirements:

- All data must be backed up to the MDSHA network on a daily basis.
- Every week, all new data is archived to a tape drive. Two copies are made of data and one copy is stored off-site.

Collection of this cracking data consists of a great deal of effort and this investment must be protected by sound backup and archival practices.

Classification and Rating

After the data has been processed for crack detection, QC'd and QA'd, the next step is to classify and rate cracks. This process is performed by WX in an automated fashion at approximately 800 miles per hour. The user simply loads the data file into the program and selects the appropriate commands to perform this function. Cracks are classified as longitudinal and transverse and location in the pavement (outside wheelpath, inside wheelpath, center, left edge, or right edge) is determined. Algorithms to perform this procedure are proprietary and are not discussed in further detail herein. Cracks are rated as low, medium or high severity by using the AASHTO cracking protocol definition and the crack width determined by the system. The net result is a text file that contains section location information and cracking data as shown in Table 2. Approximately one million rows of data are produced each year.

TABLE 2 Cracking matrix developed using MDSHA procedure

Severity Level	Outside WP	Inside WP	Between WP	Edge Crack Left	Edge Crack Right	Transverse
1 (Low)						
2 (Medium)						
3 (High)						

Data Reduction

As suggested previously, results of the crack detection process yield an incredibly large dataset. Approximately 1500 cracking data files are generated yearly and data, including right-of-way and pavement images, occupies close to a terra-byte of storage space. The classification and rating task discussed above yields raw cracking data. These data are neither intuitive nor easy to use in native form. Therefore a process has been developed to reduce data into a condition rating of 0 to 100 and corresponding condition index of very good, good, fair, mediocre, and poor. This process has been formalized in a software program known as the MDSHA Automated Distress Analysis Tool, or ADAT. ADAT also performs a suite of logic, range and trend checks on the data. Secondly, ADAT generates a progress report to document the pace of data collection and data processing. The opening screen of ADAT is shown in Figure 2.

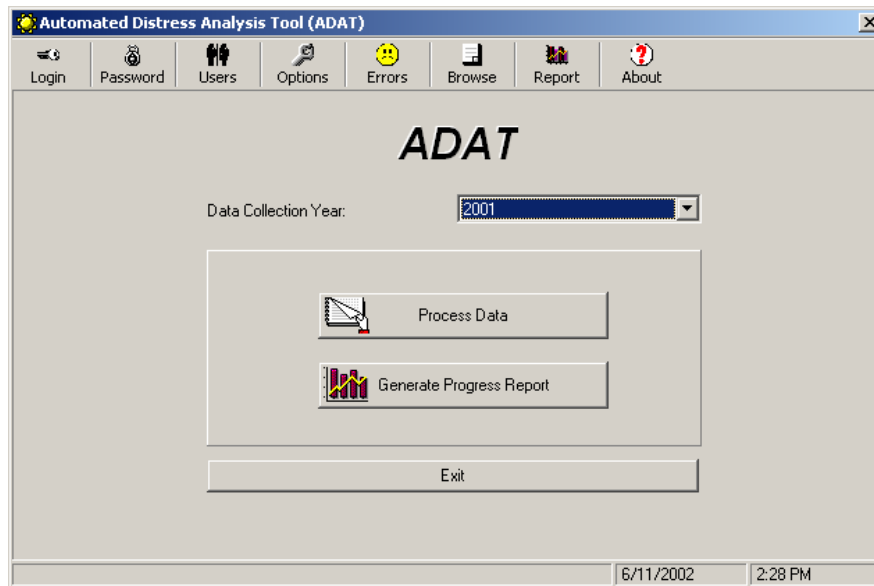


FIGURE 2 ADAT opening screen shot

When data are submitted to ADAT for processing, the program first does a complete QC check of the data. The format of this data and required field and range checks are documented in Table 3 (please note use of mixed and non-standard units in this file). If the file fails these checks, the file is flagged and a note is output to an error log. In cases where there is a fatal flaw (e.g. missing data), processing is halted.

If the file passes these checks, then processing continues. Data is converted into US units, and reformatted to match PMS specifications. The total amount of cracking is then determined and pavement condition index is calculated. In order to generate condition index, MDSHA experimented with several different algorithms. In the end, the algorithm selected was derived by combining the AASHTO protocol with methods used in the development of the PCI (3) procedure. In this procedure, cracking derived from the AASHTO procedure is summarized into total crack length for a given section consisting of severity levels of low, medium, and high (as determined by the AASHTO protocol). A deduct value is then determined using the density of cracking for each condition level and these values are adjusted and subtracted from 100 to determine the numerical rating. The numerical rating is then transformed into a condition rating. Deduct values and condition indicator breakpoints are currently being refined by MDSHA but the overall process seems to work very well and yields an indicator that is reasonable and intuitive.

In order to manage the vast amount of data, ADAT also performs a series of tasks associated with keeping track of progress achieved. Figures 3, 4, 5, and 6 illustrate example output from this process. Readers are cautioned that this is example data only. At the conclusion of the processing phase, data are summarized in tenth of a mile increments and output to the PMS in a compatible database table. This direct export from ADAT to the PMS reduces data handling procedures and ensures data integrity.

TABLE 3 Required fields and cracking range checks

Col.	Variable	Type	Units	Required ?	Allowable	Field Name
1	County Code	NUM(2,0)	n/a	Y	1-24	CODE
2	Route Number	Varchar2(8)	n/a	Y	N/A	RNUM
3	Not Used					
4	Direction	NUM(1,0)	n/a	Y	See below ¹	DIR
5	Length	NUM(6,0)	milli-miles	Y	N/A	
6	IMO File Name	VARCHAR2(8)	n/a	Y	N/A	FILE_NAME
7	Data Collection Date	DATE (mmddyy)	n/a	Y	> 1/1/2000	DATE
8	Truck Number	NUM(4,0)	n/a	Y	N/A	TRUCK_NO
9	Not Used	N/A	n/a	N	N/A	N/A
10	Event Marker	NUM(2,0)	n/a	Y	1,11,21	EVENT
11	Chainage	NUM(6,0)	milli-miles	Y	0-999,999	CHAINAGE
12	Not Used					
13	Rating/Classification Scheme	VARCHAR(20)	n/a	Y	N/A	RATING_SCHEME
14	Lane width	NUM(3,2)	M	Y	2.00-4.00	LANE_WIDTH
15	Unknown					
16	Long Left Edge Low	NUM(6,3)	M	Y	-1, 0-30	LONG_L_EDGE_LOW
17	Long Left Edge Med	NUM(6,3)	M	Y	-1, 0-30	LONG_L_EDGE_MED
18	Long Left Edge High	NUM(6,3)	M	Y	-1, 0-30	LONG_L_EDGE_HIGH
19	Long LWP Low	NUM(6,3)	M	Y	-1, 0-30	LONG_L_WP_LOW
20	Long LWP Med	NUM(6,3)	M	Y	-1, 0-30	LONG_L_WP_MED
21	Long LWP High	NUM(6,3)	M	Y	-1, 0-30	LONG_L_WP_HIGH
22	Long Center Low	NUM(6,3)	M	Y	-1, 0-30	LONG_CENTER_LOW
23	Long Center Med	NUM(6,3)	M	Y	-1, 0-30	LONG_CENTER_MED
24	Long Center High	NUM(6,3)	M	Y	-1, 0-30	LONG_CENTER_HIGH
25	Long RWP Low	NUM(6,3)	M	Y	-1, 0-30	LONG_R_WP_LOW
26	Long RWP Med	NUM(6,3)	M	Y	-1, 0-30	LONG_R_WP_MED
27	Long RWP High	NUM(6,3)	M	Y	-1, 0-30	LONG_R_WP_HIGH
28	Long Right Edge Low	NUM(6,3)	M	Y	-1, 0-30	LONG_R_EDGE_LOW
29	Long Right Edge Med	NUM(6,3)	M	Y	-1, 0-30	LONG_R_EDGE_MED
30	Long Right Edge High	NUM(6,3)	M	Y	-1, 0-30	LONG_R_EDGE_HIGH
31	Trans Low	NUM(6,3)	M	Y	-1, 0-30	TRANS_LOW
32	Trans Med	NUM(6,3)	M	Y	-1, 0-30	TRANS_MED
33	Trans High	NUM(6,3)	M	Y	-1, 0-30	TRANS_HIGH
34	Trans Count Low	NUM(3,0)	n/a	Y	-1, 0-300	TRANS_COUNT_LOW
35	Trans Count Med	NUM(3,0)	n/a	Y	-1, 0-300	TRANS_COUNT_MED
36	Trans Count High	NUM(3,0)	n/a	Y	-1, 0-300	TRANS_COUNT_HIGH

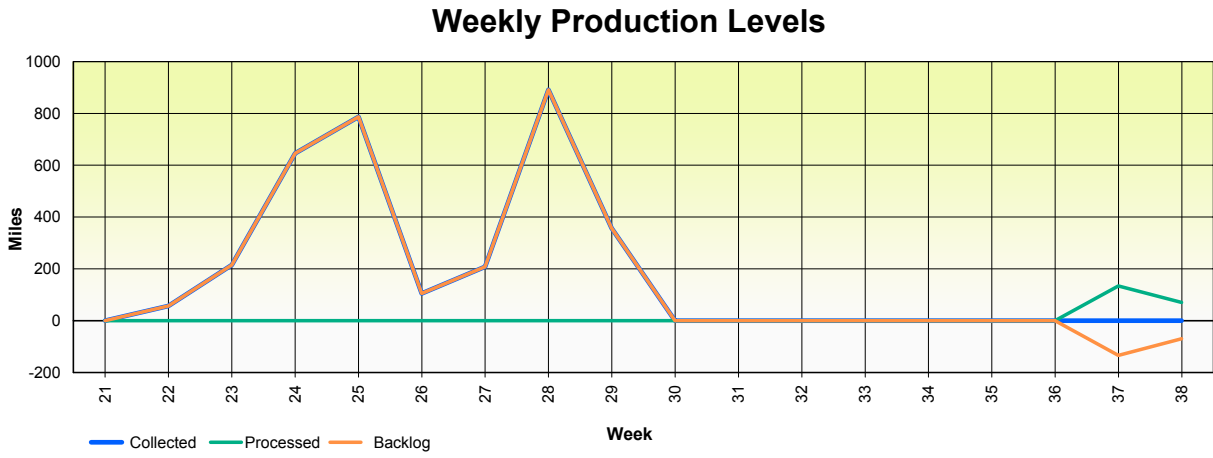


FIGURE 3 Example ADAT weekly production level graphs

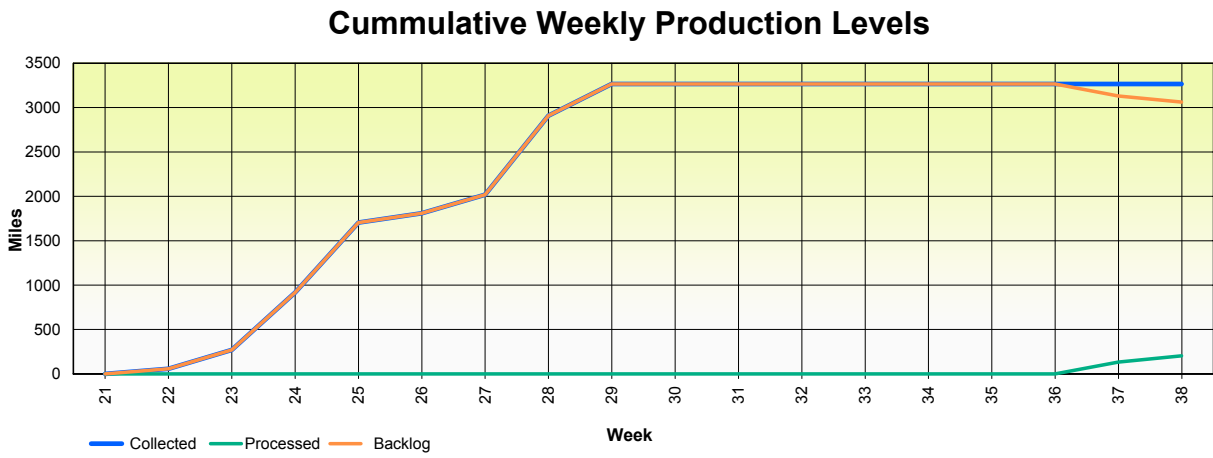


FIGURE 4 Example ADAT cumulative weekly production level graphs

Network Level Progress

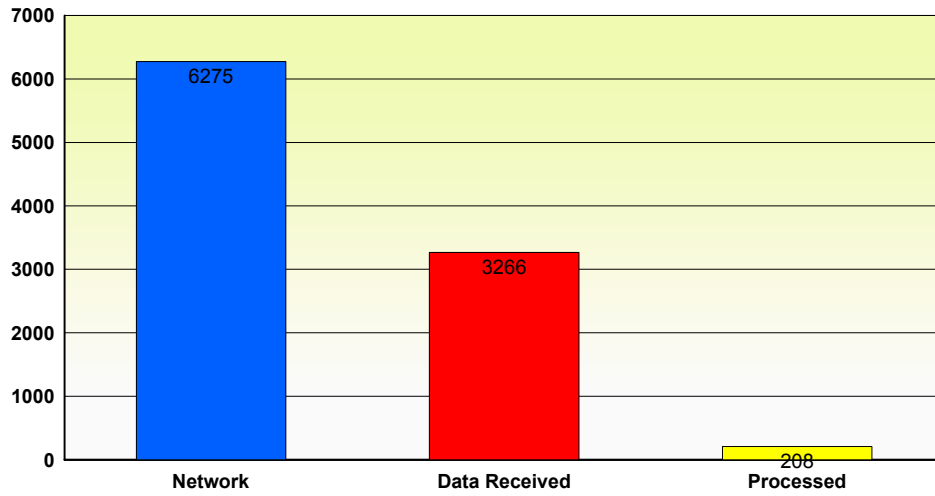


FIGURE 5 Example ADAT network level progress graph

Network Level Condition Graph

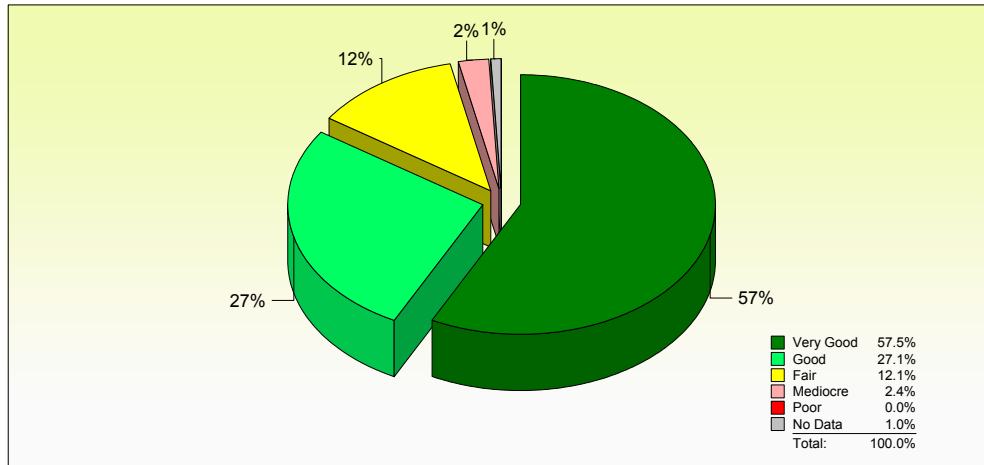


FIGURE 6 Example network level condition graph

PERFORMANCE INDICATORS

The ultimate use of the cracking data will be to provide MDSHA with an overall performance indicator to be used in PMS performance models. MDSHA is currently investigating methods with which to combine rutting, roughness, and cracking into an overall condition index (OCI). It is envisioned that this index will be a 0 to 100 indicator that has a weighting factor applied to each type of performance measurement. Frankly, the State has voluminous rutting and roughness data but we are only now generating reliable cracking data to use in this model. Therefore, MDSHA is some time off from generating this OCI.

LESSONS LEARNED

Over the past few years, MDSHA has embarked on a comprehensive plan to generate reliable cracking data using an automated process. The State has learned much about limitations and rewards of pursuing such a system. The following lists some of these lessons:

- Automated crack detection is a viable technology that is “ready for primetime.”
- Performing in-house is a large resource commitment in terms of equipment purchase, personnel training, and operator time.
- The key to quality cracking data is to take a phased approach to implementation. Take each step slowly and work out all bugs before proceeding to the next step.
- Rigorous QC and QA are paramount. Large amounts of effort should be devoted to this cause.
- Partner with the manufacturer of equipment you use. Learn from them and allow personnel to attend training offered by the vendor. More was learned in two days with the vendor than in 10 weeks on our own.
- Secure commitment from above. The implementation process is time and resource intensive and progress sometimes appears to be slow.
- Validate your data and your process at each stage of implementation. “Ground-truth” resulting data as much as possible in the field.
- Keep it as simple as possible.

SUMMARY

In this paper, several issues are discussed related to MDSHA’s automated crack detection process. MDSHA collects data on its entire network every year. This data collection occurs over a six-month period using State forces. Subsequent data processing of the pavement images to determine cracking occurs as part of a seven step process. Each of these processes is documented in some detail. Generally cracking data are generated using the proprietary WX detection system. It is emphasized that QC/QA are paramount to producing quality cracking data. Data reduction occurs using a separate piece of software developed by the State. This data reduction system outputs a 0 to 100 Pavement Condition Index value, assigns a condition rating, performs additional quality checks and helps managers keep track of progress. Finally, this paper documents lessons that have been learned by MDSHA during this process.

It is intended that presentation of this information will allow others to gain insight into the strengths and weaknesses of adopting such a system and promote information sharing among pavement data collection organizations. Overall, it is concluded that automated network level crack detection is a viable and efficient tool. However, a strict QC/QA regime must be instituted in order to achieve consistent and repeatable results.

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