A COMPARATIVE STUDY OF MONITORING METHODS IN SUSTAINABLE PAVEMENT SYSTEM DEVELOPMENT

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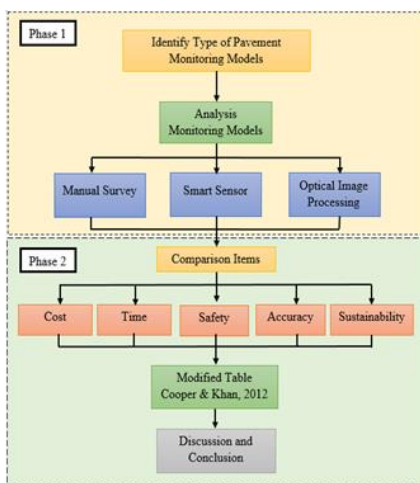[c]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Graphical abstract

Abstract

Pavement management system (PMS) has been receiving increasing attention from both the government and private sectors in the attempt to ensure and keep the roads in good condition. The appropriate level of road maintenance activity is often contingent upon the type of pavement distress. Valid and reliable pavement data would lead to develop a PMS which is more suitable for agencies. Previous studies which attempted to identify modes of monitoring pavements were limited by constraints such as cost, time, and safety. This study was conducted to review some of the pavement monitoring modes introduced in previous studies. After completing a literature review, three mostly used modes, namely manual survey, smart sensor, and optical image processing, are selected for a comparative study to determine which mode is the most effective method in terms of cost, time, safety, accuracy, and sustainability. A data quality guideline was modified to produce a rating system for ranking the modes. In conclusion, the findings of this study could provide a guideline for the government and private sectors in determining the most effective pavement monitoring mode to be used in the sustainable PMS strategy.

Keywords: Sustainable development, pavement management system, manual survey, smart sensor, optical image processing

Abstrak

Sistem pengurusan turapan semakin meraih perhatian daripada sektor kerajaan dan swasta dalam usaha untuk memastikan dan mengekalkan keadaan jalan raya yang baik. Kesesuaian aktiviti penyelenggaraan jalan adalah bergantung kepada jenis dan tahap kerosakan jalan. Data turapan yang tepat dan boleh dipercayai akan membawa kepada pembangunan sistem pengurusan turapan yang lebih sesuai kepada pelbagai agensi. Kajian lepas telah dijalankan untuk menentukan mod pemantauan turapan dan kekangannya seperti kos, masa dan keselamatan. Kajian ini telah dijalankan untuk mengkaji beberapa mod pemantauan turapan yang telah diperkenalkan dalam kajian-kajian terdahulu. Selepas menjalankan kajian literatur, tiga mod yang sering digunakan, seperti kajian secara manual, pengesan pintar dan pemprosesan imej optik, telah dipilih untuk kajian perbandingan bagi menentukan mod yang paling efektif dari segi

kos, masa, keselamatan, ketepatan, dan mampan. Garis panduan kualiti data telah diubahsuai untuk menghasilkan sistem penilaian mod-mod tersebut. Sebagai kesimpulan, dapatan kajian ini dapat menyediakan garis panduan kepada pihak kerajaan dan swasta dalam penentuan mod pemantauan yang paling berkesan untuk digunakan di dalam strategi sistem pengurusan turapan mampan.

Kata kunci: Pembangunan mampan, sistem pengurusan turapan, kajian secara manual, pengesan pintar, pemprosesan imej optik

1.0 INTRODUCTION

Pavement management system (PMS) is established by highway agencies to ensure that roads are in a good condition and serving its purpose. The American Public Works Association [1] defines pavement management as a systematic method for routinely collecting, storing, and retrieving the information required for decision-making in order to ensure that limited maintenance (and construction) dollars are prudently spent. Pavement condition survey is an important element in the pavement management process. A survey of pavement condition will provide the valuable information needed for pavement performance analysis; it is also crucial in facilitating the forecast of pavement performance, anticipating maintenance and rehabilitation requirements, establishing maintenance priorities, and allocating funds [2]. The network-level pavement asset management system (PAMS) proposed by Zhang *et al*. [3], has become an important tool in helping state highway agencies determine maintenance and rehabilitation schedules and allocating limited resources. Pavements are one of the most important infrastructures which ensure a safe and comfortable journey. However, pavement is a type of consumable material and must be replaced at an appropriate interval since they deteriorate and are damaged by applied load and the effects of surrounding factors, such as heavy traffic, unpredictable climate, etc [4]. Pavement maintenance is essential to ensure a safe travel as well as prevent traffic congestion, air pollution, and accidents [5]. Consequently, PMS is becoming increasingly important since it provides information on pavement condition, which in turn helps authorities schedule, pavement maintenance activities [3, 6, 7]. PMS has brought many benefits to the urban transportation system in the recent years [8]. In order to ensure a good road system, it is essential to continuously maintain and rehabilitate the existing road network [9]. PMS should be able to facilitate the decision making process regarding which segments of a pavement network should be preserved, maintained and rehabilitated despite the budget constraints [10]. Before making a decision on road maintenance, it is important to know the actual condition of pavement in a particular area. Different types of pavement distresses [4, 11] would probably require different treatment. Therefore, data on pavement distress is required before making a decision on the proper rehabilitation treatment to be carried out [12-14].

Several pavement monitoring methods can be employed to gather pavement distress data. Conventional methods, such as walking and riding (also known as windshield) surveys are used to monitor the conditions of pavement surface manually. In addition, pavement distress data also collected via automated surveys. Previous research on PMS were conducted to make a comprehensive assessment of the method used in pavement monitoring as summarized in Table 1. To date, the pavement management authorities worldwide, including Malaysia facing the problem to choose the most effective pavement monitoring method. A comparative study is beneficial to assist the authorities choose the most effective pavement monitoring method by using valid and reliable data to implement a PMS strategy despite the constraining factors. Thus, the aim of this study is to compare the frequently used monitoring methods, including manual survey, smart sensor study, and optical image processing in term of cost, time, safety, accuracy of data, and sustainability.

Table 1 Recent developments in PMS monitoring modes

Mode	Specific Technology	Years	Authors	Advantages	Measurement
Manual Survey	Walking Survey and Riding Survey	2004	Timm *et al.* [6]	Simple to Conduct, Less Expensive, Detailed Information Collected, Greater Amount of Coverage, Easy to Cover Entire Width of Road Section	Pavement Surface Distress: Cracks, Deformation, Surface and Edge Defects, Patch and Pothole
		2011	Wolters *et al.* [15]		
		2013	Attoh-Okine & Adarkwa [16]		
Sensors	Fiber Optic Traffic Sensor (FOTS)	2000, 2003	Cosentino & Grossman [17]	Micro bend Fiber-Optic Sensing Technology	Weigh-In-Motion (WIM), Vehicle Classification
	Capacitive Sensor	2008	Malla *et al.* [18]	Light Weight, Small Volume, Portability	Load
	Strip Strain Sensor	2008 a, b	Zhang *et al.* [19,20]	Simple and Efficient	WIM and Vehicle Classification
	Piezoelectric Transduction	2011	Lajnef *et al.* [21,22]	Self-Powered, Piezo-Floating-Gate, Array	Strain and Temperature
	Smart Pavement Monitoring System	2013		Self-Powered, Continuous, Non-Volatile Storage, Small Size, Wireless Communication, High Robustness	Strain
	Optical Fiber Bragg Grating (OFBG) Sensor	2012	Zhou *et al.* [23]	3D Monitoring	Strain
	Micro-Electromechanical System (MEMS) Sensor	2014	Yang [24]	Health Monitoring, Wireless, High Survivability	Temperature, Moisture, Strain
	Mobile Sensing Technologies	2015	Yi *et al.* [25]	Smartphone Probe Car (SPC) System, Crowdsourcing-Based	Surface Anomalies (Potholes and Bumps)
Optical Image Processing (OIP)	Digital Image Collection and Analysis, PDA	2006	Cafiso *et al.* [26]	Automated Pavement Image Collection and Distress Detection	Distress (Cracks, Potholes and Patching)
	Automatic Image Processing	2011	Chambon & Moliard [27]	Noninvasive, Crack Detection	Processed Images
In-Situ Test	Dynamic Cone Penetrometer (DCP)	2014	Ahsan [28]	Simple Method, Less Time Consuming in Practical Applications, Less Maintenance, Higher Accuracy	DCPI Profile
	Geogauge			Portable Device	In-Situ Stiffness
Geographic Information System (GIS)	GIS Model Integrated with LCA and LCO	2012	Zhang *et al.* [3]	Sustainable, Economic	Collect, Manage and Visualizing Pavement Information Data
	GIS Based Application, Geodatabase Input	2017	Acquah & Fosu [29]	User-Friendly, Cheap, Multi-Criteria Decision Analysis	Road Condition Score in Percentage

2.0 METHODOLOGY

This study was carried out with two main purposes: first, to present the pavement monitoring modes introduced by previous researchers and present a comprehensive review of each mode, and secondly to do a comparative study of three selected modes in term of five indicators, i.e. cost, time, safety, accuracy, and sustainability. The first objective of the study is achieved through a literature review in which five types of pavement monitoring modes were identified. They are manual survey, sensor study, in-situ testing, optical image processing (OIP), and geographical information system (GIS).

The second objective of this study is to conduct a comparative study of three methods which were selected based on the literature review. Two manual methods, i.e. walking and riding survey, and one smart sensor study and optical image processing each were selected for the comparative study. The three categories were chosen due to their outstanding performance in their respective category. Figure 1 shows the sequence of the method adopted in this study.
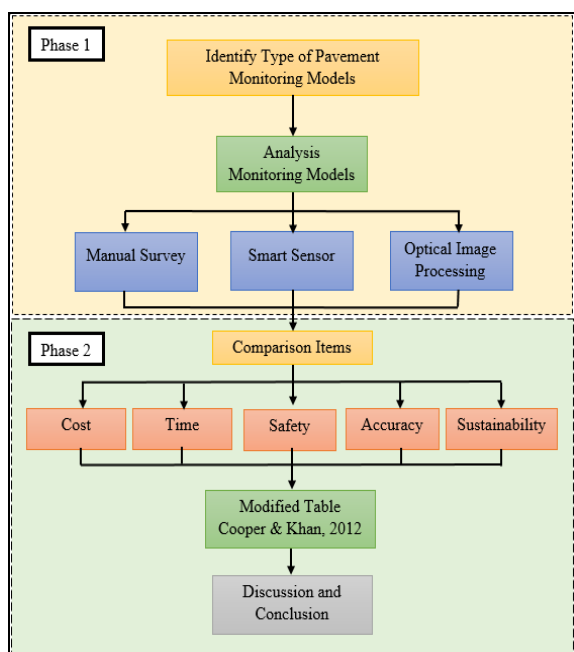
Figure 1 Conceptual Framework of the study

This comparative study used a rating system table to assign average score to each mode. The mode with highest cumulative average score for all five indicators is regarded as the most effective pavement monitoring mode. The components of the rating system are introduced through data quality guidelines [30] as shown in Table 2. The table was modified to suit the aims of this comparative study. The rank for each comparative item is arranged from worst to best. The worst rank is assigned a value of 1 and the best rank is assigned a value of 5. Table 3 presents an overall summary of the three methods. The ranking system shown in Table 4 explains the comparative items in each rank. Each mode will be given score based on the behavior of the mode. In the final stage, the score for each comparative item was summed up to compare the ranking of the modes. Finally, the result and discussion of the comparative study is presented along with a conclusion of the most effective pavement monitoring mode.

Table 2 Data quality guideline

| | Worse to Best Score | | | | |
	1	2	3	4	5
Time related coverage	More than 20 years	20 to 15 years	15 to 10 years	10 to 5 years	Less than 5 years
Geographic coverage	Data from location with different conditions and regions	Data from location with different conditions but inside regions	Data from location with same conditions but outside regions	Data from location with same conditions and inside regions	Data from previous activities in the same specific site
Precision, completeness and representativeness	incorrect assumptions, inaccurate	Missing data	Only consider energy consumption or emission, accurate	all assumptions correct, incomplete emissions data, accurate	All emissions, all assumptions correct, accurate
Consistency and reproducibility of methods used	Data acquisition methods unknown	Data acquisition difficult to reproduce	Methods are incomplete	Complete methods but unclear assumptions to be reproducible	Data from accepted test methods, steps understood, reproducible

Source: Cooper & Kahn [30]; Babashamsi [31]

Table 3 Summary of Comparison of the Modes

NO.	Comparative Items		Manual Survey		Smart Sensor	Optical Image Processing
---	---	---	Walking	Riding		
			Walking	Riding		
1	Cost	Equipment	Handheld tools or devices, data sheet	Computer, vehicle	Sensor, RF transponder and RF reader	High speed digital acquisition system, vehicle with camera, computer
		Labor & Training	- Trained evaluators - Trained for more than 6 months	- Experienced evaluators - Training required	- No labor cost - No training required	- Low labor cost - No training required
		Operation & Maintenance	- No operating cost - No maintenance fee	- Low operating cost - Low maintenance cost	- First time installation - Less maintenance due to high robustness	- Manual or software processes needed to convert the data into a usable format
2	Time		Very slow, 4 km per day	6000 km completed in 3 weeks	Very fast, continuous	Normal highway speed, 100 km/j
3	Safety		Dangerous, higher risk when gathering data	Safer, no risk	Safe, wireless communication	Safe to conduct on road
4	Accuracy		- Subjective, based on evaluator's experience - May be limited to certain span or segment of road	- May miss some data when the vehicle moves too fast	- Real time data, record and long-term data storage	- More objective measurement - Repeatability
5	Sustainability		- Use of paper, record on data sheet	- Emission of carbon monoxide gas by vehicle will cause air pollution	- Data can be read by RF reader either manually or by using a vehicle	- Emission of carbon monoxide gas by vehicle will cause air pollution

Table 4 Rating System for Comparative Items

WORSE TO BEST ➡

Compared Item	Rating System				
	1	2	3	4	5
Cost (For 1 km)	Very Expensive RM 400 and above	Expensive RM 301-RM 400	Moderate RM 201-RM 300	Cheap RM 101-RM 200	Very Cheap Below RM 100
Time (For 1000 km)	Very Slow More than 1 month	Slow 2 weeks to 1 month	Fair 1 to 2 weeks	Fast 1 to 6 days	Very Fast Less than 1 day
Safety	Very dangerous, may cause accident.	Dangerous, exposure to hazard.	Lower risk, safe.	Safe to conduct on road.	Very safe, no direct contact with traffic.
Accuracy	Inaccurate or wrong data.	Low accuracy, some missing data.	Accurate, data considered acceptable.	Accurate, most of the required data is retrieved.	High accuracy with real-time data.
Sustainability	Not related to any sustainability practices.	Does not implement sustainable practice, cause certain damage to environment.	Minimal implementation of sustainable practice, potential risk to the environment.	Sustainable practices, effort to reduce pollution.	Support overall sustainable practice, environmentally friendly.

3.0 RESULTS AND DISCUSSION

Following the tabulation of the rating system, the ranking process can be commenced by giving a score to each of the monitoring modes. The comparative items begin with cost, time, safety, accuracy, and end with sustainability.

3.1 Cost Comparison

In the present study, a new rating system was introduced for the cost indicator (Table 5) to give a more specific and detail explanation about cost allocation. Since each mode has been assigned with different types of cost, the cost indicator was divided into three categories, i.e. price of equipment, labor and training costs, and operating and maintenance cost.

Table 6 shows the scores for the average costs of all three pavement monitoring methods. The summary presented shows that manual walking survey does not require a high equipment cost. The cost for equipment in a walking survey is for handheld tools and paper; it requires the lowest cost

(score 5) when compared with other method. The given a score of the equipment cost for the smart sensor mode, is slightly higher than other modes because of the high cost of sensor equipment. Each sensor consists of several components, such as a piezoelectric transducer, a floating gate, and an RF transponder, which is the highest equipment cost (score one) among all methods. The equipment used in optical image processing includes a high-speed digital acquisition system, which essentially means a vehicle equipped with a camera, and computers might be used to compute pavement distress data.

The second cost indicator is labor and training costs. Expenses for training evaluators to conduct manual survey method cannot be avoided. A well-trained evaluator is crucial in ensuring that the survey is carried out correctly and comprehensively [6]. The labor cost for the walking survey is rather high. Evaluators must undergo over 6 weeks of training before they are qualified to conduct their walking survey under tedious condition [32]. This means that the survey is labor intensive during the data collection period. Thus, walking survey was given the lowest score for their labor and training costs. The

riding survey was given a score of two due to the fact that compared to walking survey, it is less labor intensive. Smart sensor, however, does not involve any labor and training costs during the data collection process. Thus, it was given the highest score. Optical image processing involves a low labor cost since a driver is needed for the mobile laboratory.

The third cost indicator is operation and maintenance costs. As it is shown in Table 3, manual walking survey does not involve any operation and maintenance costs. The cost of operating and maintenance in riding survey is low, where the cost incurred is vehicle operation cost (VOC). The sensors used are this study requires very little maintenance since they are self-powered and very robust. There is a first-time installation cost to embed the smart sensors under the pavement. It should be noted that, if the sensors broke down or malfunctioned, the

operation cost would be higher than those of other modes. For these reasons, the smart sensor was given the highest score in maintenance and operation. The operation cost for optical image processing method is lower compared with smart sensor. The operation cost in this method mainly for operating the vehicle and data processing. The maintenance cost in OIP comprises operation of the vehicle and ensuring that the cameras are always in a good condition. If the mobile laboratory was not maintained in a good general condition, the accuracy of the gathered data might be compromised.

According to average cost score in Table 6, manual walking survey has the highest average cost score of 3.67, which means that it has the lowest cost in comparison with other modes in this study. The smart sensor has the lowest average cost score of 2.33 (highest cost), which means that it is the most expensive method for PMS.

Table 5 Rating System for Cost Indicator

Cost Indicator	Rating System				
	1	2	3	4	5
Equipment	Very expensive	Expensive	Affordable	Cheap	Very cheap
Labor + Training	High labor and training costs	Medium labor and training costs	Low labor and training costs	Low labor cost and no training cost	No labor and training costs
Operating + Maintenance	High conducting / operating and maintenance costs	Medium conducting / operating and maintenance costs	Low conducting / operating and maintenance costs	Low conducting / operating cost and no maintenance cost	No conducting / operating and maintenance costs

Table 6 Average Cost Score ranking system

MODE		Cost Indicator			Cost Average Score
		Equipment	Labor + Training	Operation + Maintenance	
MANUAL SURVEY	Walking	5	1	5	3.67
	Riding	3	2	3	2.67
SMART SENSOR		1	5	1	2.33
OPTICAL IMAGE PROCESSING		2	4	2	2.67

3.2 Time Taking

Table 4 indicated the scores for the time indicator, where the ranking is from the slowest (score one) to the fastest (score five). The mode which completes the monitoring 1000 km segment of pavement condition in the shortest period of time is ranked as the best.

Manual survey apparently took the longest time to be completed, as have been shown in previous studies, such as the study conducted by the Arizona Department of Transportation (ADOT) [6]. Onn [32] stated that manual walking survey is very time consuming and tedious and is only able to gather data for a 4-km segment per day. This method was given a score of one. The riding survey was able to

cover a longer segment, in less time [6]. This survey was conducted using a very slow-moving vehicle [33]. The speed of the vehicle used in this survey is around 30-40 km/h since the evaluator must inspect, identify, and record pavement distresses while sitting in a moving vehicle. Onn [32] has shown that a manual riding survey which covered 1000 km was completed in three weeks. This riding survey was given score two. The smart sensor method is capable of continuously monitoring pavement strain events [22]. This mode is given the highest score by virtue of its ability to provide real time data very quickly. The smart sensors embedded below the pavement are able to store strain data less than a day old and retrieve the data very quickly. The ability of the optical image processing method to gather pavement data is dependent on the speed of the mobile laboratory. The OIP method is essentially carried out at a typical highway speed [34]. The network-level data collection method is technique which makes it possible to gather data for a large network in a relatively short period of time through the use of modern (and still evolving) technologies which automated much of the data acquisition and processing [34]. Thus, OIP mode is given a score of four for its time allocation.

3.3 Safety Assurance

Timm *et al.* [6], Wolters *et al.* [15], Xue *et al.* [8], and Attoh-Okine and Adarkwa [16] contended that manual survey exposes evaluators to hazards during data collection. For this reason, ADOT only conducts surveys when the weather permits [6]. Many states are currently transitioning or have made the transition from manual pavement condition surveys to automated pavement condition surveys due to safety and efficiency issues which are present in manual condition surveys [6]. The safety indicators for the walking survey mode are presented in Table 3. Table 4 shows the ranking used for the danger and hazard exposure. The walking survey was given a score of two while the riding survey was given a score of three due to the lower risk. The evaluators conducting riding survey are not exposed to the dangers of being on the road side. Instead the survey was done with the evaluators being driven in a vehicle. The smart sensor mode does not expose evaluators to any kind of hazard. This method does not require any human involvement subsequent to its installation. Hence the smart sensor mode is given a score of 4 which means that in can be safely conducted on the road. The data retrieval method in OIP is similar to manual riding survey where the data is retrieved while riding on a moving vehicle. The main difference between the two methods is that in the riding survey data collection is done by humans (manually) while in OIP it is done using a digital camera (automated). Attoh-Okine and Adarkwa [16] reported that among the benefits of automated distress survey (such as OIP) is safety for survey crews and faster and more objective data. Optical image

processing was given a score of four in terms of safety. This method is given a better score than riding survey since the evaluator in the vehicle does not have to deal the problem of missing data because all the data will automatically be recorded by the cameras. Therefore, the OIP mode offers a much safer method for collecting data.

3.4 Data Accuracy

The fourth item compared in this study is accuracy of data. The availability of a more accurate data would allow agencies to make better decision with regard to their PMS strategy. Attoh-Okine and Adarkwa [16] indicated that the data collected through manual walking survey tend to more subjective and less accurate since it is influenced by evaluators' experience. According to Bogus *et al.* [18], it is not uncommon for manual distress surveys to result in disparity of data. The disparity in distress data is a critical issue in the attempt to improve the effectiveness of pavement condition index as a reliable indicator and useful tool for pavement management systems (PMSs). Even though evaluators must undergo training prior to working in the field, the dataset produced by experienced and inexperienced evaluators will invariably be different. Prakash *et al.* [35] compared the disparity in the data gathered by experienced (at least 5 years of experience) and inexperienced evaluators. The research concluded that, to improve the quality of manual distress data, evaluators must undergo regular training, and they should be tested to identify and minimize evaluator's bias with regard to specific distresses. It should be noted that manual walking survey is sometimes limited to a certain segment of the road [34]. Humans have limited ability and it is not possible for any evaluator to survey the entire route if the distance is too long. Hence walking survey is given a score of three, which means that the data is considered acceptable. Riding survey could produce even less accurate data when compared with walking survey. The evaluator might not notice pavement distress due to the high speed of the vehicle if data collection is not automated. All observations, inspection, identification and recording should be done by a trained individual. Transcription error could occur, especially when evaluators try to record the information in a record book within a very short span of time. This error was presented on the discussion from a study by Attoh-Okine and Adarkwa [16]. Hence, riding survey is given a score of two, which indicates low accuracy since data could be erroneously recorded or missed during the data collection process. The design of sensors used in the smart sensor mode makes it possible for compute and store data in a long period as well as recording data automatically in real time. Lajnef *et al.* [22] have shown that these sensors are very robust and functions continuously. This mode has very high accuracy and hence is given the highest score. The accuracy of the OIP mode is higher than manual

survey and gives an objective evaluation of the pavements. This mode can be repeated if there is a need to do multiple runs over the entire road width. According to Attoh-Okine and Adarkwa [16] this system utilizes five mounted video cameras, i.e. two in front, two in the rear, and one each on top and in the center. Each camera covers a span of about 30 square feet (2.8 square meters) with a 50% overlap at 55 mph (below 90 km/h). The research also found that the automated OIP mode could cover the footprint of data collection vehicle. Therefore, the accuracy from this mode is not as good as that of the smart sensor. This mode is given a score of four which indicates that this mode is accurate and is able to gather most of the required data.

3.5 Sustainability and Environmental Impacts

Regarding sustainable development, pavement asset management systems should be able to account for sustainability indicators, such as user time delay caused by preservation activities, additional fuel consumption caused by deterioration of pavement surface, and other environmental impacts [3,36]. Two factors in manual walking survey could have positive/negative influence on sustainability. Since this is the only mode which requires walking in the data collection stage, it could consider as an environmentally-friendly mode. It does not cause air pollution or impact assessment of carbon emission into the environment. On the other hand, usage of paper data sheets (to record the pavement distress data) makes this method less sustainable rather than digital data storage. The use of paper can be replaced with other handheld tools or devices which would allow data to be gathered digitally. The manual walking survey is given a score of three based for its sustainable approach. In the riding survey, the risk to environment is via the release of carbon monoxide produced by the vehicle. This problem can be avoided by using eco-friendly vehicles which would reduce gas emission that contribute to air pollution. Unlike walking survey, most riding surveys use digital data collection technique since the vehicles can be fitted with electronic devices, such as computer, to conduct the survey. Evaluators would be able to record the data digitally and can even easily and directly input the data into appropriate software. For these reasons, riding survey was given a score of four with regard to sustainability. The smart sensor mode can be considered as an eco-friendly mode. The use of automatic and self-

powered sensor has eliminated the need to use vehicles during the data collection process. This also means that there is no gas emission. Vehicles are only used periodically to retrieve data via wireless communication from the RF reader. Data retrieval can also be done manually if the distance for data retrieval is not too far. The smart sensor mode was given a score of five for sustainability. In this study, the OIP mode was given a score of three since a customized van was used to conduct the survey due to the difficulty in obtaining an eco-friendly car. Cameras and electronic devices were mounted to the mobile laboratory. Thus, the problem of carbon monoxide emission cannot be avoided.

Once the scoring process for each of the modes in five comparison items has been completed, the average scores were computed, and the results are shown in Table 7. The mode with the highest average score is considered as the most effective pavement monitoring mode. The smart sensor mode has the highest average score of 4.27. The optical image processing mode has the next highest score of 3.53. The scores for walking and riding methods are almost similar, with the riding survey showing a slightly better score than walking survey. Both manual surveys (walking and riding) are ranked the lowest, with the walking survey having a score of 2.73 and riding survey a score of 2.53.

4.0 CONCLUSION

The present study reviewed five major pavement-monitoring modes (Manual Survey, Sensors Studies, Optical Image Processing, In-situ Test and Geographic Information System) which have been conducted in previous studies. Three modes were chosen for a comparative study, i.e. manual survey (comprising walking and riding surveys), smart sensor, and optical image processing. Comparison was done base on five indicators, i.e. cost, time, safety, accuracy and sustainability, to determine which mode is the most effective in performing pavement monitoring functions. Results show that the smart sensor method is the best overall mode for pavement monitoring. As a conclusion, it is hoped that the findings of this study would help relevant agencies make a decision with regard to the most effective pavement monitoring mode for their PMS strategy relative to the constraining factors they may have.

Table 7 Average Score of the Five Indicators

MODE		Cost	Time	Safety	Accuracy	Sustainability	Average Score
MANUAL SURVEY	**Walking**	3.67	1	2	3	3	2.53
	Riding	2.67	2	3	2	4	2.73
SMART SENSOR		2.33	5	4	5	5	4.27
OPTICAL IMAGE PROCESSING		2.67	4	4	4	3	3.53

Acknowledgement

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