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RESEARCH PAPER

Development of a Road-Condition Assessment System and Application to Road Maintenance Decision-Making

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ABSTRACT: The deterioration of existing road pavement surfaces over the years due to aging and the growing number of heavy vehicles has become an important issue. Roads require appropriate maintenance to keep providing the target service. Many efforts have been made by road engineers to maintain road pavement surfaces; however, there are some problems due to costs, including vehicle running costs. Therefore, there is a need for an efficient and low-cost system to facilitate evaluation of the serviceability of existing road pavement surfaces. This study aims to develop an efficient, rational and useful method or system that can be used to perform a visual assessment of the condition of not only the pavement but also road structures, including slopes, vegetation and equipment such as guardrails, curbs and guideposts. Such a system should be inexpensive and be IT-based by making use of new information and the latest technologies. In addition, a method based on an analytic hierarchy process is employed in the decision-making process to analyze a complicated decision problem based on video files obtained by the system.

Keywords: Analytic Hierarchy Process (AHP), Assessment System, Decision Making, Ippo-Campo, Road Condition, Road Network, Timor-Leste.

1. Introduction

Road networks are one of the most important key infrastructures that contribute to rapid economic growth. At the same time, there is an increasing demand for reasonable preventive maintenance, including repairs to the road pavement and other facilities within the road networks while the roads remain in service, despite limited budgets and human resources.

Regarding the road pavement, for example, the Maintenance Control Index (MCI) is used in Japan as an index for judging damage to asphalt pavements (Miyamoto et al., 2009). MCI parameterizes the cracking ratio, roughness and rutting depth, but it can also be used as an index based on two attributes or even just one attribute (CESFJ, 1993). MCI inspection of the road pavement is undertaken using a specially designed vehicle (Government of Japan, 2008).

In the United States, the current level of serviceability of a pavement is expressed using the Present Serviceability Index (PSI)

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developed by the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 1993). Another useful index is the international roughness index (IRI) proposed as an indicator by the World Bank (Sayers, 1985), which mainly focuses on ride quality and the roughness of road surfaces, including but not limited to asphalt pavements. The IRI is an index defined by applying an algorithm to a measurement of the longitudinal profile.

For the indices mentioned above, the soundness of the road pavement is usually evaluated by using an inspection vehicle. Such a vehicle is capable of accurate quantitative evaluation, but its initial and operating costs are usually relatively high, and such vehicles tend to be used infrequently. Another constraint is that this inspection vehicle cannot measure the road width, radius of curvature and slope. In addition, there are many features of a road that must be regularly checked, such as road appurtenances and filled/cut slopes. Therefore, there is a need for an efficient and low-cost system to facilitate evaluation of the serviceability of an existing road pavement surface. This paper introduces a newly developed road condition assessment system (called Ippo-Campo) and its practical application to road maintenance decision-making. Ippo-Campo is a pavement maintenance evaluation system based on a moving vehicle and obtains data from a motion sensor, as well as video, sound and GPS data. It is a simple evaluation system that provides a systematic and consistent approach to the evaluation of the condition of a pavement surface. In addition, the video file produced by Ippo-Campo can be used for making a multi-criteria-based decision by using the analytical hierarchy process (AHP). This supports decision making with regard to complex sustainability issues and can help to recognize and define a problem in detail. The results of AHP provide a useful means of checking the consistency of evaluation measures and alternatives to reduce bias in decision-making. It is helpful for particular conditions and distress types and enables the prioritization of necessary repairs and maintenance work within limited budgets.

2. Research Significance

Road deterioration due to inadequate and untimely maintenance is likely to lead to an increase in the number of traffic accidents, reduced reliability of transport services and increased vehicle operating costs. Therefore, there is a need for an appropriate maintenance method to ensure that a road can provide a sustainable service (Modarres and Shabani, 2015; Zhao et al., 2018). The main aims of the work described in this paper are to apply a road condition assessment system to road networks in both Japan and Timor-Leste to confirm the effectiveness of the system and also to apply the system to decision making for road maintenance by using the AHP model for the road networks of Timor-Leste, which is a developing country, as a specific example.

3. Development of a Road-Condition Assessment System

3.1. Concept of the System

This section gives a brief overview of how data analysis is performed. Data are obtained using a three-dimensional motion sensor, a GPS system equipped with a gyro and an acceleration sensor, a high-resolution camera, and a microphone. Figure 1 shows the equipment installed in a vehicle. It takes about 20 min to install and start-up the measuring equipment. The system sensor acquires GPS log data. Thus, the acceleration, time (GMT), angular velocity, geomagnetic and orientation sensor information, an orbital plan view and satellite reception conditions can be recorded. The GMT time is very important for synchronizing the video information with the sensor information. In addition, items displayed on this screen can be selected independently, and the scale of the viewing area can be arbitrarily set

(Miyamoto et al., 2013). Figure 2 shows an example of the system's signal display. The noise from the car and the car's motion data, as obtained from the video and the motion sensor, are obtained from a car travelling along a selected road. The recommended speed of the car is 50 km/h to 60 km/h. It is possible for one person (the driver) to check the status of the installation of the equipment and capture the data (Hugo et al., 2014).

3.2. Configuration of the System

An evaluation of the road pavement condition using the Ippo-Campo assessment system and the obtained three-dimensional motion sensor, video and sound data involves several steps. Figure 3 shows an example of the system's menu screen. It was developed using Visual Basic in Microsoft Excel (Miyamoto et al., 2013). Figure 4 shows the configuration of the system functions. Motion sensor data, driving video data, sound data, subtitle data and GPS data are acquired by the system. By connecting these data, an evaluation of the road surface ("GOOD", "MODERATE" or "BAD") is output to an Excel file every second, together with the longitude, latitude, X and Y coordinates, point distance, etc. In addition, by linking the system with online maps by using the GPS data, the evaluation results can also be displayed on a map. Then, by converting the world geodetic system into latitude and longitude information, it is possible to reflect the results of the evaluation on road register map data (Hugo et al., 2014).

3.3. Determination of Threshold Values for the System

The determination of the threshold points for the pavement surface uses the standard deviation of the Z-axis acceleration signal. The threshold was decided by conducting a road surface measurement test as part of a cooperative study undertaken by Yamaguchi Prefectural Government and Yamaguchi University. The defined value was obtained by evaluating the data between the MCI and the Z-axis acceleration. The results assumed that the threshold levels for pavement management for the standard deviation of the Z-axis acceleration are: 0 to 0.4 for "GOOD", which is indicated in green and with the ○ symbol; 0.4 to 0.6 for "MODERATE", which is indicated in yellow and with the △ symbol; and more than 0.6 for "BAD", which is indicated in red and with the X symbol. Figure 5 shows the correlation between the MCI and the standard deviation of the Z-axis acceleration. The regression equation and correlation coefficient are derived from the relationship between the MCI standard and the obtained Z-axis acceleration data. It is assumed that the value of 0.4 for the standard deviation of the Z-axis acceleration is equivalent to an MCI of ≥ 6, which represents the "GOOD" condition of the road pavement. A value of 0.6 for the standard deviation of the Z-axis acceleration is equivalent to an MCI of ≥ 5, which represents the "MODERATE" condition of the road pavement. Moreover, a value of ≥ 0.6 for the standard deviation of the Z-axis acceleration is equivalent to an MCI of ≥ 5, corresponding to the "BAD" condition of the road pavement (Hugo et al., 2014).

Table 1 shows an example of the output data in an Excel file. Figure 6a shows an example of a video and subtitle file that illustrates the road situation using video, and Figure 6b shows an example of output data indicating the condition of the road as web map data, showing the road condition using three highlighted colors: red for bad, yellow for moderate, and green for good.

On the other hand, the Timor-Leste threshold was determined by using the average value for the data obtained from the measurement points by using the system, because Timor-Leste has no established method with which a comparison can be made. In addition, the Japanese thresholds (0.4 to 0.6) shown in Figure 5 are not applicable to Timor-Leste road surfaces because the conditions are completely different. Therefore, we randomly selected a measurement point from the best road conditions in Timor-Leste and analyzed the obtained data using the system.

Fig. 1. Arrangement of measuring equipment installed in a car

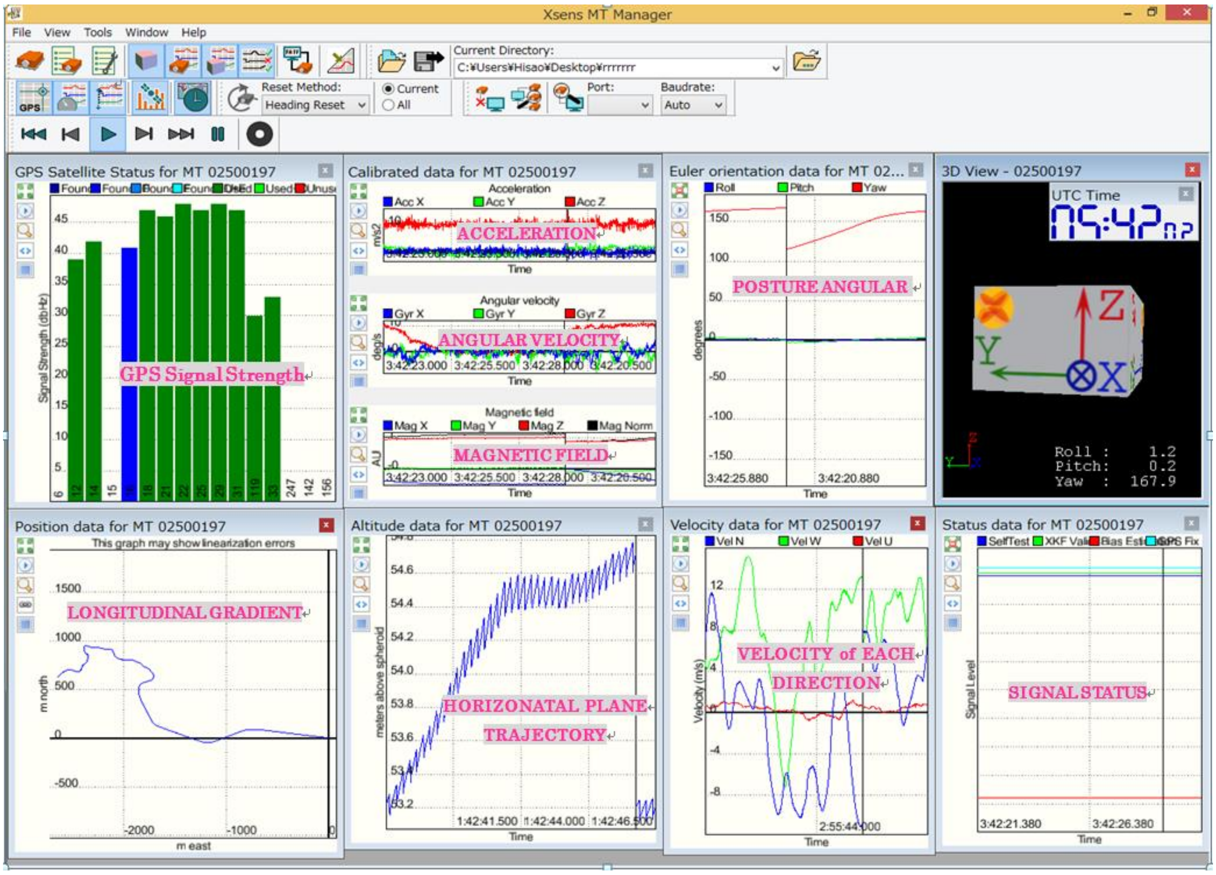


Fig. 2. Example of signal display in the system

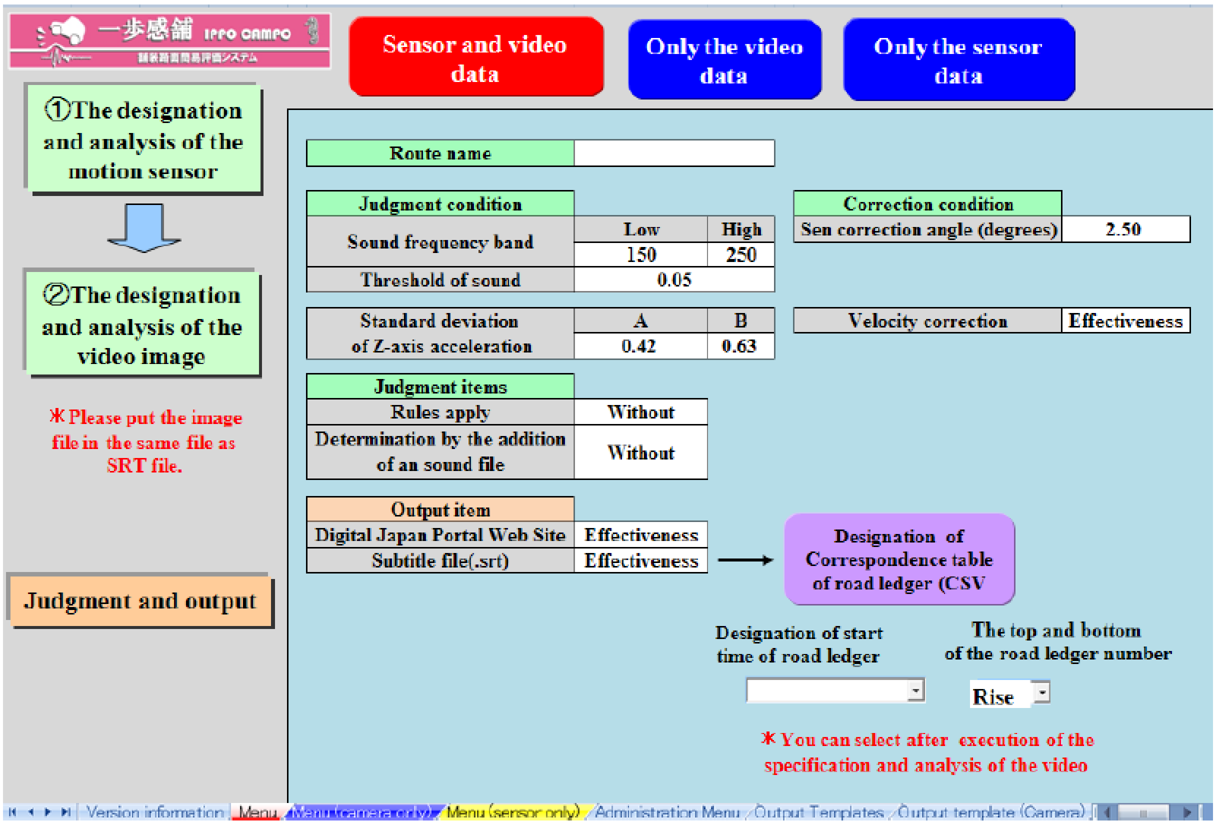


Fig. 3. Menu screen of the road condition assessment system

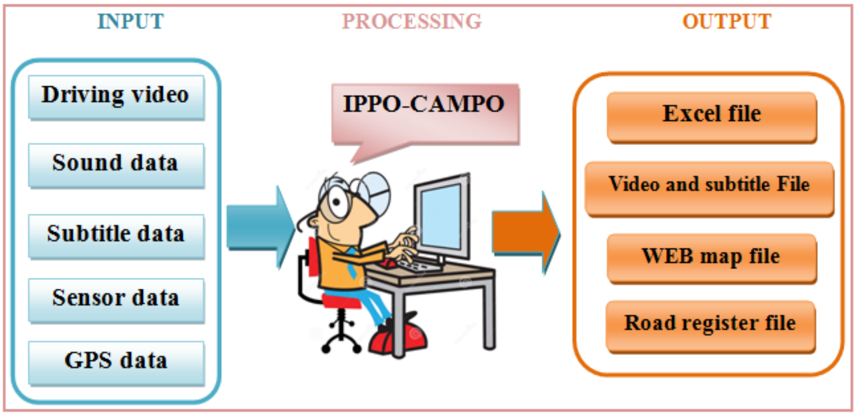


Fig. 4. Configuration of the system functions

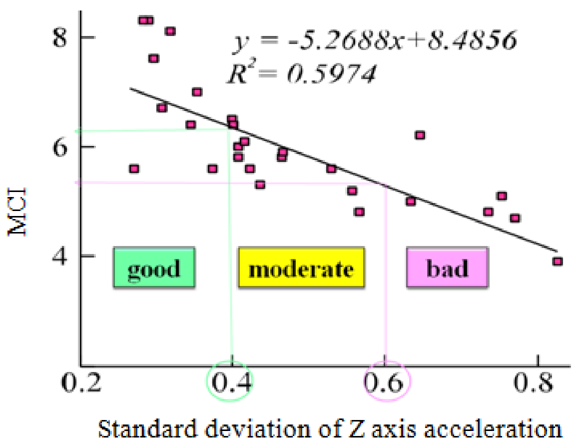
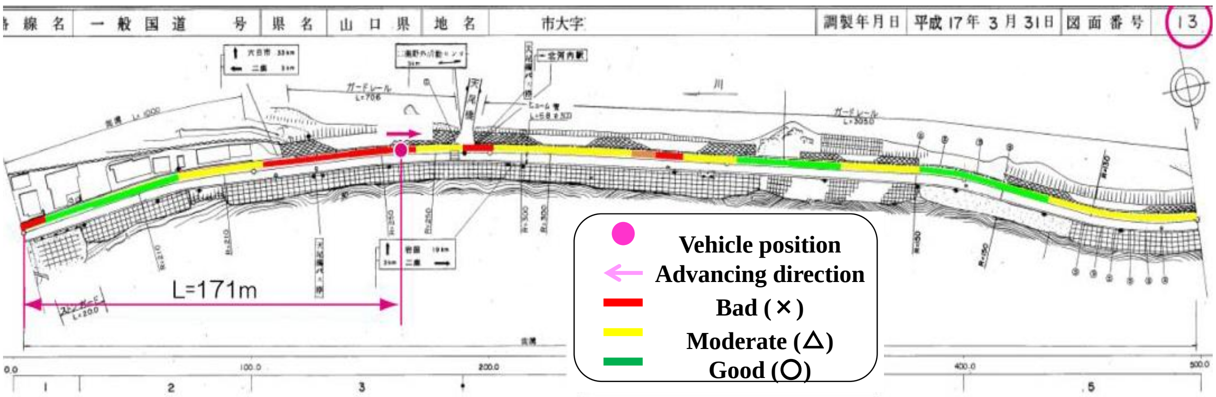


Fig. 5. Correlation between MCI and standard deviation of Z axis acceleration

Table 1. Example of output data of evaluation results in an Excel file

10	JST	Latitude	Longitude	Map	Point distance	Cumulative distance	Longitudinal gradient	Number of satellites	Judgment
553	2012/2/16 16:08:20	34.17839	132.0643	Map	14.07224488	6350.2716	−2	7	○
554	2012/2/16 16:08:21	34.17839	132.0642	Map	12.65927545	6362.930875	−2	7	△
555	2012/2/16 16:08:22	34.1784	132.064	Map	14.1230363	6377.053912	−1.3	7	△
556	2012/2/16 16:08:23	34.17841	132.0639	Map	14.12303446	6391.176946	−0.9	7	△
557	2012/2/16 16:08:24	34.17843	132.0637	Map	14.22408505	6405.401031	−0.7	7	×
558	2012/2/16 16:08:25	34.17845	132.0635	Map	15.61633777	6421.017369	−0.5	7	×
559	2012/2/16 16:08:26	34.17847	132.0634	Map	14.22407889	6435.241448	0.3	7	×
560	2012/2/16 16:08:27	34.17845	132.0635	Map	12.91129266	6448.152741	1	7	×
561	2012/2/16 16:08:28	34.17852	132.06331	Map	14.29311293	6462.445854	2.8	7	×

(a)



(b)

Fig. 6. a) Example of evaluation results using video file with subtitles; and b) Example of evaluation results using web map file

Furthermore, because of the different conditions of the road surfaces between the two countries, we chose a trial threshold of 0.7 to 1.2 for application to the Timor-Leste road networks. Then we tried to analyze the data that was eventually used to compare the evaluation results for both the Japanese and Timor-Leste thresholds (see Figure 7). Table 2 shows how the threshold for Timor-Leste was determined. In this measurement, we obtained 1,377 items of data: 182 for the "GOOD" condition, 452 for the "MODERATE" condition, and 743 data for the "BAD" condition. Red is clearly the dominant color, implying that the condition of the road is poor. On the other hand, for the evaluation using the trial threshold (0.7 to 1.2), the number of items for the "GOOD" condition increased to 781, the number of items for the "MODERATE" condition increased to 490, and the number of items for the "BAD" condition decreased significantly to 106. In this case, green is the dominant color, implying that the condition of the road is "GOOD". As result, the threshold for Timor-Leste was decided by defining 0 to 0.7 as the "GOOD" condition, 0.7 to 1.2 as the "MODERATE" condition, and more than 1.2 as the "BAD" condition, as shown in Figure 7.

Table 2. Evaluation results obtained with Ippo-Campo system using different thresholds

// Start Time: 13/05/2015 - 00:38:34			ルール適用: 無し					Japanese thresholds (0.4~0.6)			Trial Threshold (0.7~1.2)	
// Sample rate: 100.0Hz			音声判定付加: 無し									
// Scenario: 2.7			センサファイル名: MT 02500197 000-000.txt									
// Firmware Version: 2.6.1			ビデオファイル名: 20150513093841.m2ts									
音声周波数帯域: 150 - 250			SRTファイル名: 20150513093841.m2ts.srt					good	182	max	4.826305094	781
音声閾値: 0.05			計測時刻補正値: 0(s)					moderate	452	ave	0.732784209	490
加速度閾値(x): 0.42 < x < 0.63			センサ補正角度: 2.5(度)					bad	743	min	0.248342478	106
電子国土ポータル:	Dili-Erm 20150513.htr		速度補正: 有効						1377			1377
JST	Latitude	Longitude	X座標	Y座標	地図	点間距離	累加距離	縦断勾配(%)	判定	Acc_Z	Z軸加速度標準偏差	
2015/5/13 9:38:41	-8.55652	125.579	-4937488	-726698	地図	1.8E-10	1.08E-09	-12.8311501	○	9.76084	0.383642075	○
2015/5/13 9:38:42	-8.55652	125.579	-4937488	-726698	地図	1.8E-10	1.26E-09	-12.78674537	○	9.766366	0.349702399	○
2015/5/13 9:38:43	-8.55652	125.579	-4937488	-726698	地図	1.8E-10	1.44E-09	-12.69275586	×	9.756204	0.642628799	○
2015/5/13 9:38:44	-8.55652	125.579	-4937488	-726698	地図	1.8E-10	1.62E-09	-12.66133336	○	9.774447	0.357976721	○
2015/5/13 9:38:45	-8.55652	125.579	-4937488	-726698	地図	1.8E-10	1.8E-09	-12.60151351	○	9.780256	0.349523589	○
2015/5/13 9:38:46	-8.55652	125.579	-4937488	-726699	地図	0.845386	0.845386	-12.21586745	△	9.804959	0.493905926	○
2015/5/13 9:38:47	-8.55652	125.579	-4937488	-726699	地図	0.106191	0.951577	-11.53450111	×	9.821707	0.643425627	○
2015/5/13 9:38:48	-8.55653	125.579	-4937488	-726700	地図	0.871521	1.823098	-11.41005554	×	9.811538	0.731937321	△
2015/5/13 9:38:49	-8.55653	125.5789	-4937488	-726702	地図	2.544805	4.367903	-11.57819365	×	9.798709	0.87266775	△
2015/5/13 9:38:50	-8.55653	125.5789	-4937488	-726705	地図	2.544925	6.912827	-11.59939091	×	9.806535	0.815876303	△
2015/5/13 9:38:51	-8.55653	125.5789	-4937489	-726707	地図	2.555854	9.468681	-11.61403045	×	9.790099	0.724866878	△
2015/5/13 9:38:52	-8.55654	125.5789	-4937489	-726711	地図	3.396176	12.86486	-11.81704374	△	9.789932	0.566167683	○
2015/5/13 9:38:53	-8.55654	125.5788	-4937490	-726715	地図	4.238579	17.10344	-12.07585332	△	9.781413	0.554497024	○
2015/5/13 9:38:54	-8.55654	125.5788	-4937490	-726719	地図	4.238579	21.34202	-12.18002829	×	9.844116	0.652649982	○
2015/5/13 9:38:55	-8.55654	125.5788	-4937490	-726724	地図	5.081973	26.42399	-12.10744228	×	9.767702	1.062019582	△
2015/5/13 9:38:56	-8.55655	125.5787	-4937491	-726730	地図	5.925714	32.3497	-12.50891841	△	9.882396	0.502547031	○
2015/5/13 9:38:57	-8.55655	125.5786	-4937491	-726736	地図	5.925825	38.27553	-11.95982021	×	9.790152	0.700601242	△
2015/5/13 9:38:58	-8.55655	125.5786	-4937492	-726743	地図	6.775858	45.05138	-11.9595101	△	9.831685	0.555440249	○
2015/5/13 9:38:59	-8.55656	125.5785	-4937492	-726750	地図	7.626415	52.6778	-11.97283511	×	9.80172	0.650536003	○
2015/5/13 9:39:00	-8.55657	125.5784	-4937493	-726759	地図	8.485803	61.1636	-11.86189786	×	9.739823	0.914276356	△
2015/5/13 9:39:01	-8.55657	125.5784	-4937494	-726766	地図	7.681509	68.84511	-12.14703612	×	9.79478	0.921112067	△
2015/5/13 9:39:02	-8.55659	125.5783	-4937496	-726776	地図	9.371631	78.21674	-12.33087979	×	9.786565	0.655448561	○
2015/5/13 9:39:03	-8.5566	125.5782	-4937497	-726784	地図	8.565114	86.78186	-12.55208111	△	9.80505	0.562006388	○
2015/5/13 9:39:04	-8.55661	125.5781	-4937499	-726793	地図	9.416492	96.19835	-12.33565631	△	9.754033	0.5077247	○
2015/5/13 9:39:05	-8.55662	125.578	-4937501	-726802	地図	8.582866	104.7812	-12.52860175	△	9.755717	0.563241303	○
2015/5/13 9:39:06	-8.55664	125.578	-4937502	-726811	地図	9.433836	114.2151	-12.47858504	×	9.774732	0.655902668	○
2015/5/13 9:39:07	-8.55665	125.5779	-4937504	-726820	地図	9.416605	123.6317	-12.4889252	△	9.765231	0.589245	○
2015/5/13 9:39:08	-8.55667	125.5778	-4937506	-726830	地図	9.416515	133.0482	-12.15836094	△	9.798956	0.543859687	○
2015/5/13 9:39:09	-8.55668	125.5777	-4937507	-726838	地図	8.548653	141.5968	-12.3214707	○	9.694976	0.397876912	○
2015/5/13 9:39:10	-8.55669	125.5776	-4937509	-726846	地図	8.565104	150.1619	-12.62738381	△	9.738771	0.450777043	○
2015/5/13 9:39:11	-8.5567	125.5776	-4937510	-726856	地図	9.371532	159.5335	-12.77876843	×	9.750595	0.63757966	○
2015/5/13 9:39:12	-8.55671	125.5775	-4937511	-726863	地図	7.681645	167.2151	-12.74237816	△	9.725966	0.55213003	○

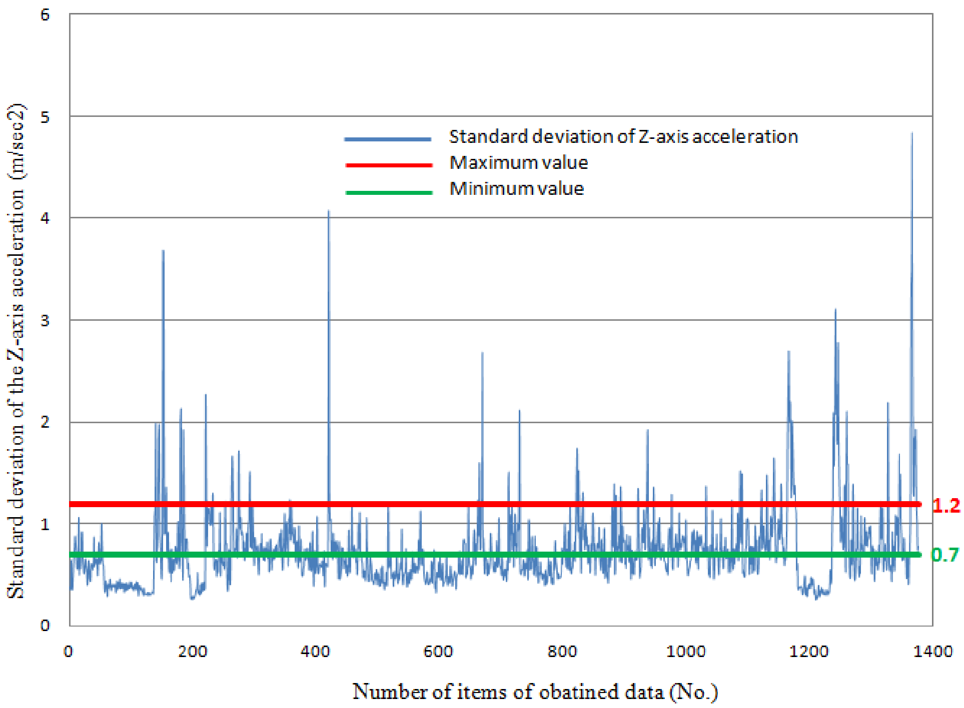


Fig. 7. Thresholds assumed for Timor-Leste

3.4. Determination of Evaluation Signal Using a Motion Sensor

The determination of the evaluation signal was made by choosing a target route and conducting measurements to understand the degree of change in the sensor data before and after pavement repair work. The measurement was performed four times. Two measurements were performed in April and May 2010 to determine the road condition before the pavement repair, and the other two were conducted in August 2010 and January 2011 to determine the condition after the pavement repair.

The evaluation signal consists of two standard deviations, sound data, and acceleration data. It is obtained by analyzing the relationship between the standard deviation and the sound data for the road surface. The sound data was obtained by running a sound test in the test car. The movement of the car along the road resulted in road noise in a frequency band of 20 to 20,000 Hz. The frequency band of the road noise produced when traveling over a road surface with irregular roughness was around 10 to 1000 Hz. Therefore, to analyze the frequency band representing the condition of the road surface, the sound data at 10,000 Hz was divided using a sound band-pass filter (BPF). Figure 8 shows how the band was partitioned into three ranges: 50 to 150 Hz, 150 to 250 Hz, and 200 to 300 Hz. The data in the 50 to 150 Hz and 200 to 300 Hz bands are not suitable for use as sound evaluation signals (Miyamoto et al., 2013). However, the sound data for the 150 to 250 Hz band is suitable for use as an evaluation signal because it is clearly discernible, despite having different values before and after the pavement repair work (Hugo et al., 2014).

Meanwhile, the evaluation signal for the acceleration data was also obtained. Figure 9 shows the standard deviation of the acceleration using three-axis vehicle vibration data. It illustrates that the X and Y-axis accelerations are not suitable for use as an evaluation signal. However, the Z-axis acceleration is suitable for use as an evaluation signal because it is clearly discernible despite having different values before and after the pavement repair work.

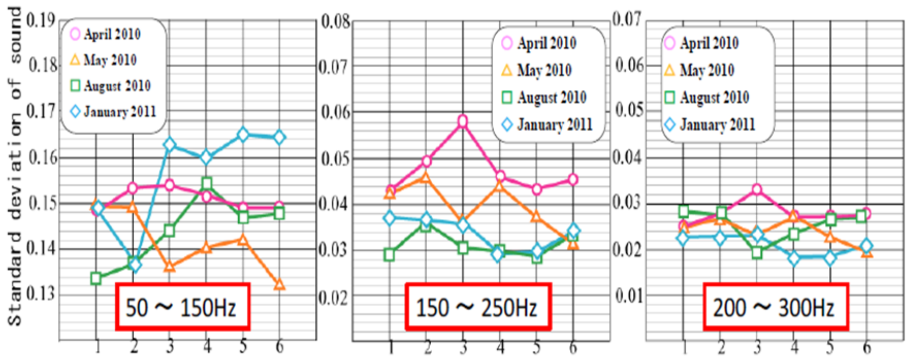


Fig. 8. Standard deviation of sound of running vehicle for various frequencies

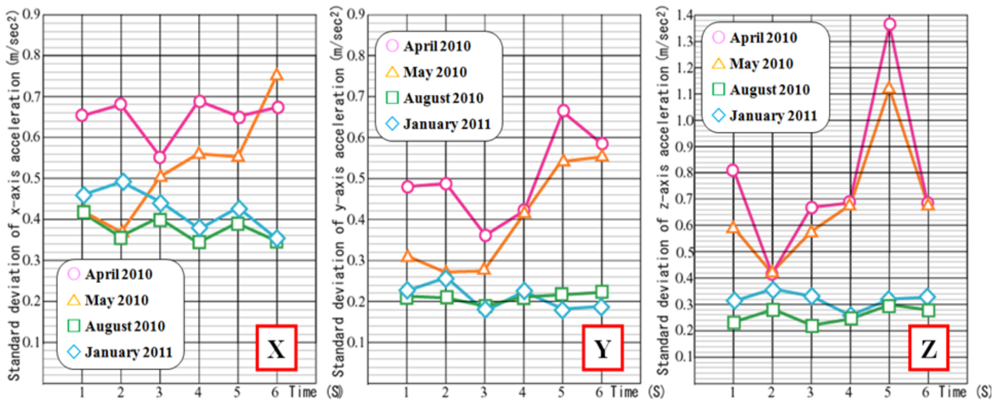


Fig. 9. Standard deviation of the acceleration obtained from vehicle vibration data

3.5. Determination of Dependent Velocity of the System

The dependent velocity of the system was determined by evaluating the velocity change of a vehicle while in motion to determine the influence on the evaluation signal. The study was conducted on a public road by using a vehicle to drive over concrete blocks placed in front of both front wheels, as shown in Figure 10. This examination was performed to obtain the data for the pavement surface by changing the velocity of the vehicle. Starting with a velocity of 5 km/h, the velocity range for the examination was 20 to 50 km/h over a distance of 30 m (Hugo et al., 2014). Figure 11 shows the result of the examination; it shows the relationship between the velocity and the standard deviation of the Z-axis acceleration in the evaluation signal. The data illustrates that the standard deviation increases with the velocity of the vehicle. Therefore, the regression equation and correlation coefficient were derived from the relationship between the evaluation signal and the velocity, defined as follows (Miyamoto et al., 2013).

$$y = 0.0061x + 0.00937 \quad (1)$$

where y: is the standard deviation of the Z-axis acceleration (m/s^2), and x: is the vehicle velocity (km/h). Eq. (1) is used as a speed correlation formula for outputting the evaluation result of a road pavement surface.

Fig. 10. Set-up in measurement vehicle

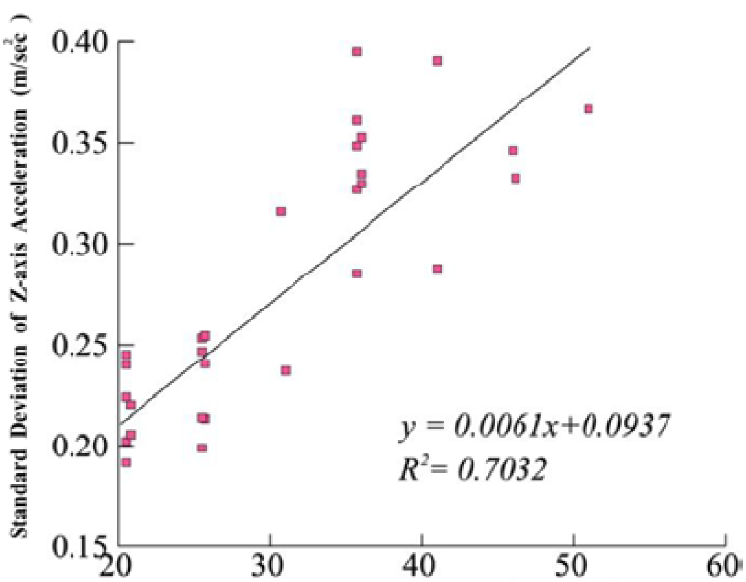


Fig. 11. Relationship between velocity and standard deviation of Z-axis acceleration

4. Practical Application of System to Road Networks

4.1. Road Conditions in Timor-Leste

Timor-Leste is one of the least developed countries in Southeast Asia. Its nonoil economy is characterized by slow and unstable growth, even though there has recently been recent strong growth in urban centers, particularly in the capital city. The economy is essentially agriculture-based, with about 72% of the total population of 1.1 million living in rural areas. Subsistence farming is the main livelihood of a large majority of the rural people, with limited production of agricultural products, mostly coffee, for cash income. The Asian Development Bank (ADB) has announced that agricultural productivity in Timor-Leste is low compared with other countries in the region (ADB Timor-Leste, 2013).

Roads constitute the primary mode of transport in Timor-Leste, carrying 70% of all freight and 90% of passengers. The road network was constructed to the Indonesian pavement standard of 4.5 m wide, with a lined masonry drain. The road networks also consist of a national road that links the districts together, district roads that link the district centers to the sub districts, and rural roads that provide access to the villages and the more remote areas. Overall, however, the road networks are in a poor condition due to the limited budget and resulting lack of maintenance. The ADB study affirmed that, due to the poor condition of the rural roads, rural people face increased travel times and transportation costs and are isolated in terms of access to social and economic facilities and services, such as local markets, schools, health facilities, job opportunities, government services, and banking services (ADB of Timor-Leste, 2013).

4.2. Application of Road Condition Assessment System to Road Networks in Japan and Timor-Leste

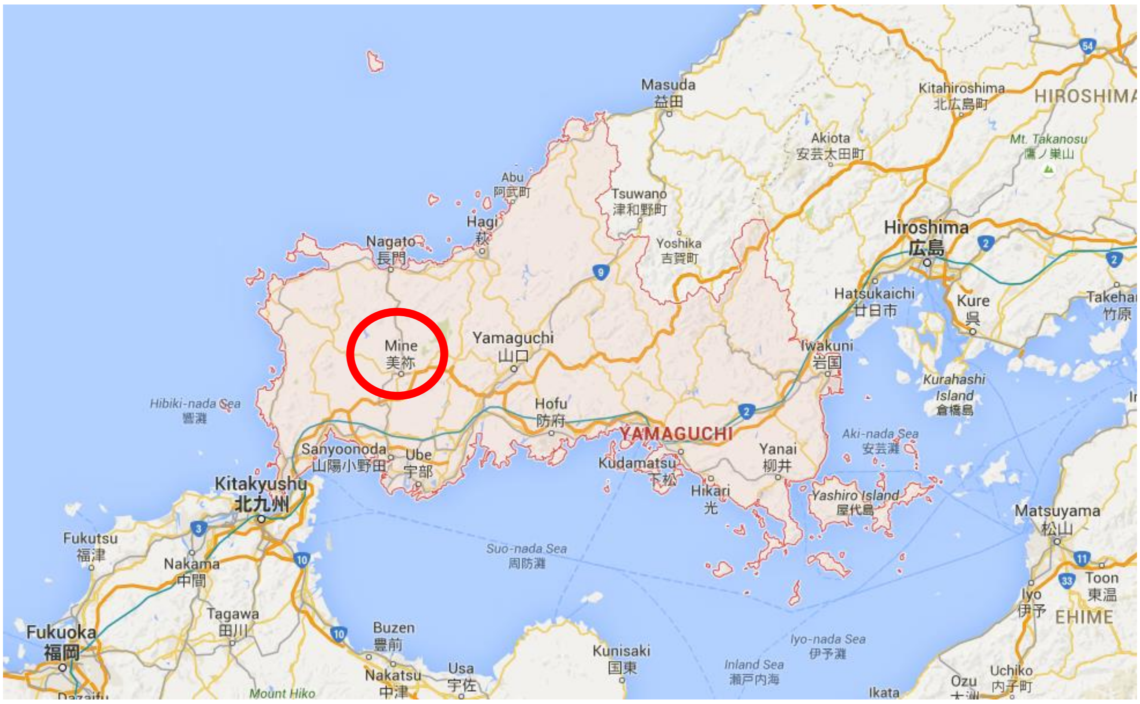
The Ippo-Campo system was designed for application to road surface pavement maintenance. The system was designed for Japan's roads, where it has established itself as a capable IT-based system. The use of an IT-based system makes it easier to obtain output results effectively and efficiently within the limited budget for the present condition of a road. Therefore, it was assumed that the system can be applied in other countries as well, especially developing countries. In this study, we applied the system to a few actual road networks for evaluating the effectiveness and workability of the system. To that end, we conducted measurements in two countries, namely, Japan and Timor-Leste. In Japan, the assessment of the road pavement was conducted for the road networks of Mine City in Yamaguchi Prefecture, as shown in Figure 12a (Miyamoto, 2019).

4.2.1. Target Road Route in Mine-City, Japan and Application of the System

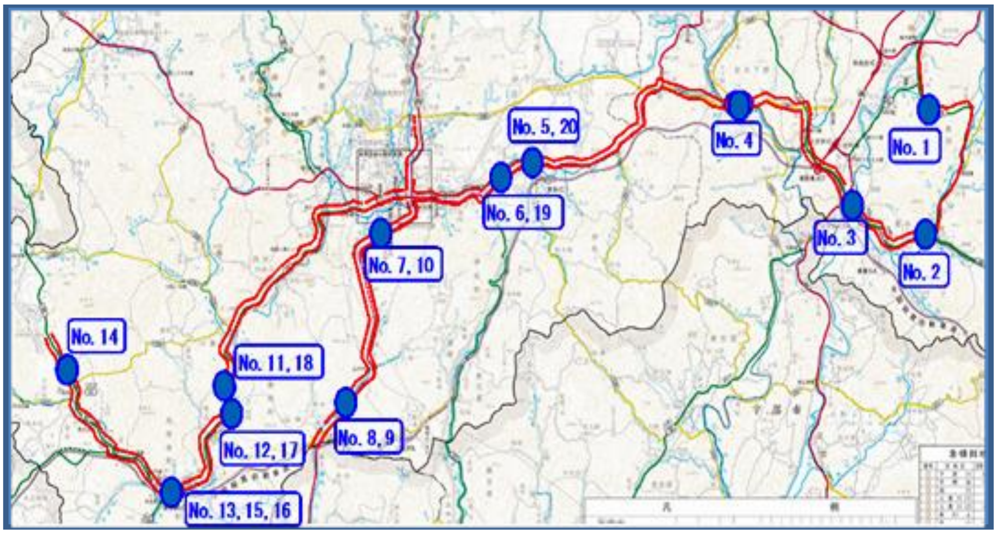
The assessment of the road pavement condition was conducted in the road network in the Mine City (Yamaguchi Pref., Japan) jurisdiction, under the responsibility of the "Ube Civil Engineering Mine branch office". As shown in Figure 12b, the target roads are also located in Mine City, and the total distance of the measured road is 8,050 m. Table 3 lists the details of the road (line) names, types of road and the distance of each target road route. The reason for conducting the field test in Mine City is that the Yamaguchi Prefectural Government was carrying out repair work on the road pavement in this location. The measurement was performed in two ways. First, the "Ube Civil Engineering Mine branch office" conducted a road evaluation by using a patrol car. The objective was to collect information on the depth of ruts with a maximum volume of more than 40 mm^3. Second, measurements were conducted by using Ippo-Campo.

4.2.2. Measurement Details

In this study, the road measurement data was obtained using a sedan-type car. The car was driven at a speed of 50-60 km/h, and the Mti-G configuration sampling rate was 100 Hz. The measurement was done with two recording methods: from the start point to the end point, and overturn. Measurements were taken before and after repairs to the road pavement. The objective of the measurement was to compare the results obtained under both conditions and to confirm the efficiency of the system. The confirmation evaluation result of the output data used GPS data, movie data and road register data. Measurements were taken at one-second intervals. As shown in Table 4, the system recorded the condition of the road every second and recorded the time (Japan System Time (JST)). In this practical application, there are some important matters that must be excluded to prevent a decrease in efficiency of data measurement, such as a small sample number (less than 4 points), expansion joints on bridges, railways, tunnels and traffic jams, because these would cause incorrect evaluation.



(a)



(b)

Fig. 12. a) Location of Mine City, Yamaguchi Prefecture, Japan; and b) Detailed map information and numbering of the target road route

Table 3. Detailed information about the target road route

No.	Type of road	Road (line) No.	Road (line) name	Length (m)
1	Prefecture road	28	Ogouri Misumi line	350
2	Prefecture road	31	Mito line	400
3	Prefecture road	31	Mito line	550
4	Prefecture road	240	Yunoguchi Mine line	700
5	National road	435	435 line	600
6	National road	435	435 line	200
7	National road	316	316 line	650
8	National road	316	317 line	350
9	National road	316	318 line	350
10	National road	316	319 line	650
11	Prefecture road	33	Shimonoseki Mine line	300
12	Prefecture road	33	Shimonoseki Mine line	350
13	Prefecture road	33	Shimonoseki Mine line	400
14	Prefecture road	65	Sanyou Toyota line	200
15	Prefecture road	33	Shimonoseki Mine line	400
16	Prefecture road	33	Shimonoseki Mine line	150
17	Prefecture road	33	Shimonoseki Mine line	350
18	Prefecture road	33	Shimonoseki Mine line	300
19	National road	435	435 line	200
20	National road	435	435 line	600

4.2.3. Results and Discussion

The data verification results in Table 4 show an example of a road repair point. The highlighted sign indicates the repair interval and the output result obtained by using Ippo-Campo. It also illustrates the condition before and after repair. The upper part of the table shows how bad the road condition was before repair, which is dominated by × symbols. However, the bottom part of the table shows the road condition after repair, which is dominated by ○ symbols, signifying that the road was in good condition. The total number of road pavement repair points was 57, which excluded 23 points where the number of samples was less than 4. Two data processing methods were used: calculating the standard deviation of the Z-axis acceleration, and combining the Z-axis acceleration with the sound data.

Table 5 shows the remaining samples that had more than 4 samples and the result of comparing the road pavement conditions before and after repairs. The results show that the comparison percentage between the number of bad points and the total number of samples for the condition before repair is considerably higher than the percentage after repair. It was also found that there are five missing samples (sample No. 4, 8, 9, 24 and 32) where the percentage of bad points did not change because the rut depth was bigger than the width of the wheel path.

4.2.4. Application to Timor-Leste Road Networks

First, the measurements described above were conducted in Mine City road networks because the Yamaguchi Prefectural authorities repaired the road pavement. It was thought that this road network would be representative of the road network of a developed country. On the other hand, the road network in Timor-Leste was assumed to be representative of a road network of a developing country. The roads in Timor-Leste are not in a good condition; therefore, the road used for comparison was divided into only two categories, namely, “VERY GOOD” and “VERY BAD”. The purpose of this activity was to identify differences in the road conditions for different levels of service in both countries by comparing road condition data obtained using the Ippo-Campo system. The research was conducted under the supervision of Yamaguchi University in cooperation with the teaching staff of the Dept. of Civil Engineering of Universidade Nasional Timor Lorosa’e (UNTL). UNTL is the only public university in Timor-Leste that partners with the government to provide human resources for contributing to the development of the country. Therefore, the assessment process for the research, including the determination of the target routes, was decided based on the priority target line set by the government of Timor-Leste, for the development and improvement of well-connected and coherent road networks and other key infrastructures (Government of Timor-Leste, 2011).

Table 4. Verification results of pavement condition before and after repairs

JST	Cumulative distance	Repair interval	Z-axis acc.	Velocity of the car	Judgement using Z-axis acc.	Judgement using Z-axis acc. and sound data
Before repair						
2013/2/23 9.26.03					×	×
2013/2/23 9.26.04					×	×
2013/2/23 9.26.05	0.0		0.343	52.8	×	×
2013/2/23 9.26.06	14.7		1.222	52.8	×	×
2013/2/23 9.26.07	29.3		0.203	52.8	×	×
2013/2/23 9.26.08	43.8		0.362	52.8	×	×
2013/2/23 9.26.09	58.4		0.972	52.8	×	×
2013/2/23 9.26.10	73.1		0.347	52.8	O	×
2013/2/23 9.26.11	87.8		0.376	52.0	O	O
2013/2/23 9.26.12	102.2		0.266	51.8	O	O
2013/2/23 9.26.13	116.6	1	0.243	51.8	O	O
2013/2/23 9.26.14	131.0		0.306	54.3	O	O
2013/2/23 9.26.15	146.6		0.246	52.0	O	O
2013/2/23 9.26.16	160.5		0.223	53.6	O	O
2013/2/23 9.26.17	175.4		0.239	52.8	O	O
2013/2/23 9.26.18	190.0		0.285	53.6	O	O
2013/2/23 9.26.19	204.9		0.247	52.0	O	×
2013/2/23 9.26.20	219.4		0.204	53.3	O	☆
2013/2/23 9.26.21	234.2		0.202	53.6	O	☆
2013/2/23 9.26.22					△	△
2013/2/23 9.26.23					O	O
After repair						
2013/11/16 10.20.23					O	O
2013/11/16 10.20.24					O	O
2013/11/16 10.20.25	0.0		0.267	32.1	O	O
2013/11/16 10.20.26	8.9		0.267	32.1	O	O
2013/11/16 10.20.27	17.8		0.250	32.4	O	O
2013/11/16 10.20.28	26.8		0.324	37.9	O	O
2013/11/16 10.20.29	37.4		0.210	36.9	O	O
2013/11/16 10.20.30	47.6		0.308	40.9	O	O
2013/11/16 10.20.31	59.0		0.231	39.9	O	O
2013/11/16 10.20.32	70.1		0.243	43	O	O
2013/11/16 10.20.33	82.0	1	0.224	41.4	O	O
2013/11/16 10.20.34	93.5		0.208	43	O	O
2013/11/16 10.20.35	105.4		0.224	44.5	O	O
2013/11/16 10.20.36	117.8		0.283	44.5	O	O
2013/11/16 10.20.37	130.1		0.215	46	O	O
2013/11/16 10.20.38	142.9		0.200	46	O	O
2013/11/16 10.20.39	155.7		0.207	48.3	O	O
2013/11/16 10.20.40	169.1		0.206	46	O	O
2013/11/16 10.20.41	181.9		0.200	47.5	O	O
2013/11/16 10.20.42	195.1		0.193	48.7	O	O
2013/11/16 10.20.43	208.6		0.204	45.7	O	O
2013/11/16 10.20.44					△	△
2013/11/16 10.20.45					×	×

Table 5. Comparison between before and after pavement repair using acceleration and wheel sound

No	Type of road	Line No.	Line name	Length	Before repair: number of sample (S)	Before repair: X☆△ (B)	Before repair: B/S (%)	Before repair: B/S < 50%	After repair: number of sample (S)	After repair: X☆△ (B)	After repair: B/S(%)	Validity
1				200	17	9	53		19	0	0	
2	Prefecture	28	Ogouri misumi line	310	23	16	70		25	4	16	
3	Prefecture	31	Mito line	480	39	32	82		36	3	8	
4	Prefecture	31	Mito line	450	31	4	13	!	32	2	6	
5	National	435	435 line	270	21	16	76		20	0	0	
6	National	316	316 line	580	41	39	95		41	2	5	
7	National	316	316 line	420	27	23	85		28	4	14	
8				170	16	7	44	!	14	0	0	
9				80	7	2	29	!	6	1	17	
10	National	316	316 line	270	17	17	100		21	1	5	
11	National	316	316 line	600	37	37	100		31	2	6	
12	Prefecture	33	Shimonoseki Mine line	320	23	16	70		23	5	22	
13	Prefecture	33	Shimonoseki Mine line	200	14	14	100		12	3	25	
14				150	11	11	100		11	0	0	
15	Prefecture			150	10	6	60		11	2	18	
16		65	Sanyou Toyota line	440	30	19	63		26	4	15	
17				420	29	20	69		25	8	32	
18				140	11	9	82		9	1	11	
19				120	10	8	80		9	2	22	
20	Prefecture	33	Shimonoseki Mine line	100	7	7	100		8	1	13	
21	Prefecture	33	Shimonoseki Mine line	170	10	10	100		12	2	17	
22	Prefecture	33	Shimonoseki Mine line	180	13	7	54		12	5	42	
23	Prefecture	33	Shimonoseki Mine line	320	22	12	55		21	3	14	
24	Prefecture	33	Shimonoseki Mine line	80	9	4	44	!	5	1	20	
25				160	12	6	50		12	1	8	
26				150	10	10	100		11	3	27	
27				160	12	12	100		12	5	42	
28				230	15	11	73		15	6	40	
29	National	435	435 line	290	21	19	90		20	7	35	
30	National	435	435 line	520	38	38	100		45	18	40	
31				590	37	37	100		37	8	22	
32				250	17	5	29	!	16	3	19	
33				230	15	10	67		16	2	13	
34				250	15	9	60		61	6	10	

Figure 13 shows the target routes for the research. Table 6 lists the road routes and the corresponding distances, which together give a total distance of 740.3 km, and which are regarded as national priority roads connecting the capital city to the district cities of Timor-Leste.

Table 7 summarizes the results of evaluating the road conditions of the "GOOD" condition roads. The comparison used the Japanese and Timor-Leste thresholds as shown in Figures 5 and 7 (Miyamoto et al., 2013; Hugo et al., 2014). The length of the selected road for both conditions was 16 km. The result of the comparison clearly produced a different analysis result when using the proposed system. It can be seen that the use of the Japanese threshold for the selected road resulted in 12.02% being judged as being "GOOD", 34.05% as being "MODERATE", and 53.93% as being "BAD". On the other hand, the results of the evaluation changed significantly after applying the Timor-Leste threshold. This resulted in 55.95% being judged as being "GOOD" and 26.71% being "MODERATE", while the ratio of "BAD" fell to 17.35%.

The road conditions for a “BAD” condition road in Timor-Leste where evaluated, as shown in Table 8. When using the Japanese thresholds, the results show that the road was in a very bad condition. Only 0.08% of the road surface was found to be in “GOOD” condition, 4.10% was in “MODERATE” condition, and 95.82% was in “BAD” condition. At the same time, the evaluation result did not change even when the Timor-Leste threshold was used. A “GOOD” result was obtained for only 6.84% of the roads, while “MODERATE” was assigned to 41.35% and “BAD to 51.81%.

Figure 14 shows the results of evaluating a “GOOD” road in Timor-Leste. It can be seen that the use of both thresholds gives detailed information on the actual condition of this road. The threshold values play an important role in defining the standard deviation of the Z-axis evaluation (see Figures 1 and 2). This figure is just a small part of the road section. The selection of the interval uses a critical value obtained by calculating the statistical regression every second. For Japanese thresholds, this indicates that the condition is overwhelmingly” MODERATE”.

Table 6. Comprehensive evaluation of road attributes for Timor-Leste road networks

	Strength	Durability	Safety	Workability	Maintenance	Comprehensive evaluation
Retaining wall	0.4814	0.4034	0.1348	0.5338	0.3428	0.3831
Drainage	0.1207	0.3512	0.0857	0.2381	0.3305	0.2179
Culverts	0.0663	0.1243	0.0509	0.1224	0.1424	0.0987
Debris and land slide removal	0.0983	0.0729	0.2818	0.0614	0.1105	0.1103
Tree and grass cutting	0.2334	0.0481	0.4467	0.0443	0.0738	0.1666
Sum	1.0	1.0	1.0	1.0	1.0	1.0

Fig. 13. Timor-Leste road network and routes targeted by the study

Table 7. Evaluation results for GOOD condition road in Timor-Leste using both thresholds

Thresholds	Evaluation results (%)			
	GOOD	MODERATE	BAD	Total
Japanese	12.02	34.05	53.93	100
Timor-Leste	55.95	26.71	17.35	100

Table 8. Evaluation results for BAD condition road in Timor-Leste using both thresholds

Thresholds	Evaluation results (%)			
	GOOD	MODERATE	BAD	Total
Japanese	0.08	4.1	95.82	100
Timor-Leste	6.84	41.35	51.81	100

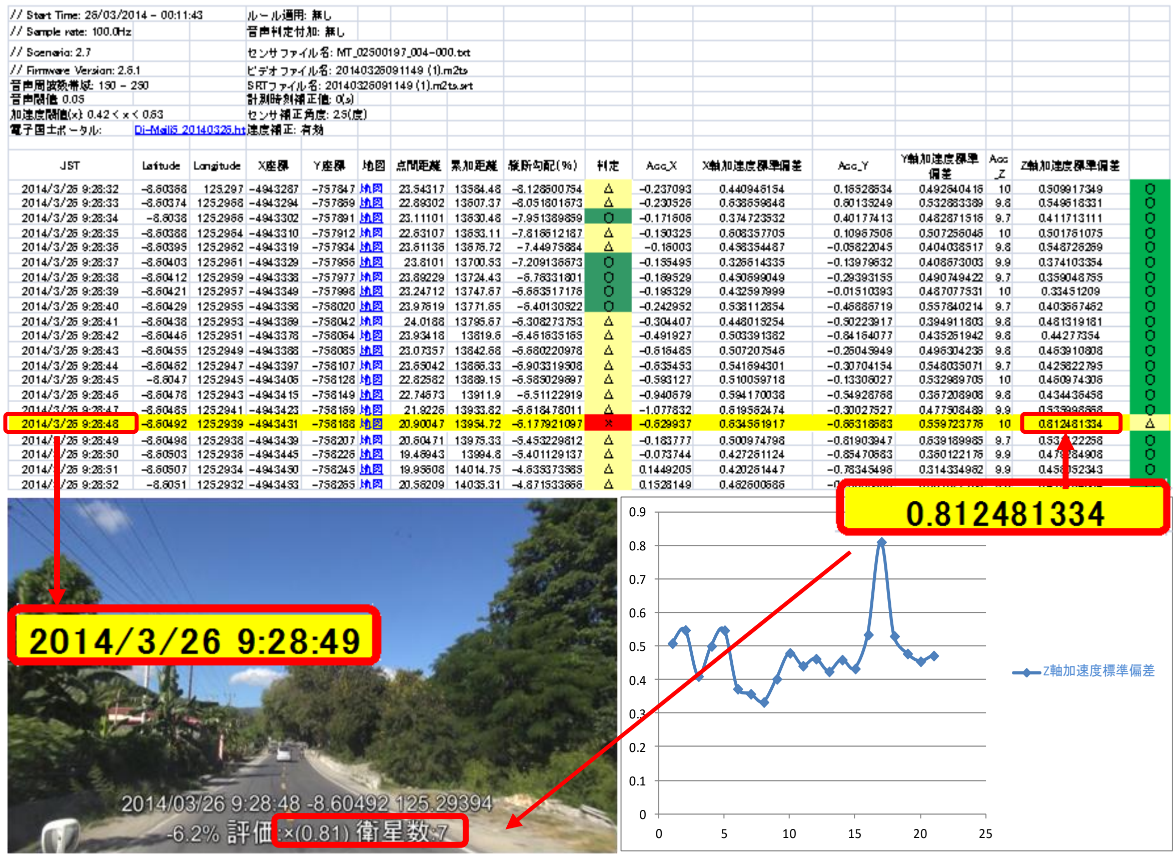


Fig. 14. Evaluation result for GOOD Timor-Leste road, obtained using Ippo-Campo

Only a few items of data indicate the “GOOD” condition, and only one item of data corresponds to the “BAD” condition. However, this condition changes significantly after using the Timor-Leste threshold. Most condition changes are from “MODERATE” to “GOOD”. It can be seen that the maximum value of the Z-axis acceleration occurs at 0.812. The evaluation results can also be seen in the video data and Excel data, together with the time information and the status of the condition of the road.

Figure 15 shows an example of an evaluation result for a “BAD” condition road. It can be seen that the use of thresholds plays an important role in making a judgment as to the actual condition of the road.

Using the Japanese threshold, the result shows that the road is in a very bad condition, relative to a rural road in Japan. Only two items of data indicate the “MODERATE” condition and none indicate that the road is in the “GOOD” condition. However, the condition changes slightly after using the Timor-Leste threshold, even if the condition is still dominated by the red color of the bad condition. It can be seen that the critical value reaches a maximum at 5.111, as shown in the Excel data and the video data.

// Start Time: 25/03/2014 - 00:53:28 ルール適用: 有り
// Sample rate: 100.0Hz 音声判定付加: 無し
// Scenario: 2.7 センサファイル名: MT_02500197_004-000.txt
// Firmware Version: 2.6.1 ビデオファイル名: 20140325095330 (2).m2ts
音声周波数帯域: 150 - 250 SRTファイル名: 20140325095330 (2).m2ts.srt
音声閾値: 0.05 計測時刻補正値: 2(s)
加速度閾値(x): 0.42 < x < 0.63 センサ補正角度: 2.5(度)
電子国土ポータル: _20140325.html 速度補正: 有効

JST	Latitude	Longitude	X座標	Y座標	地図	点間距離	累加距離	縦断勾配(%)	判定	Acc_X	X軸加速度標準偏差	Acc_Y	Y軸加速度標準偏差	Acc_Z	Z軸加速度標準偏差	
2014/3/25 10:16:31	-8.64618	125.5798	-4947464	-726435	地図	2.116517	8433.403	-9.14006186	×	-0.330442	0.621749672	0.9684249	1.10428635	9.75107	1.651180332	×
2014/3/25 10:16:32	-8.64619	125.5798	-4947465	-726438	地図	2.837352	8436.24	-7.664971539	×	-0.448747	0.716303429	0.9860052	0.768997915	9.767073	2.125073038	×
2014/3/25 10:16:33	-8.6462	125.5798	-4947467	-726439	地図	2.182078	8438.422	-5.837467521	×	-0.269116	0.707681858	1.0386716	0.867800988	9.774726	2.075737005	×
2014/3/25 10:16:34	-8.64621	125.5798	-4947468	-726441	地図	2.116517	8440.539	-5.884805397	×	-0.03251	0.602196343	0.1885875	0.465222016	9.733055	2.213232421	×
2014/3/25 10:16:35	-8.64622	125.5797	-4947469	-726443	地図	2.054356	8442.593	-9.416527138	×	-0.364799	0.384945927	0.2217246	0.559592054	9.630501	1.923259539	×
2014/3/25 10:16:36	-8.64623	125.5797	-4947471	-726445	地図	2.837352	8445.43	-10.17299984	×	-0.116684	0.685425093	0.4551759	0.616439797	9.65618	2.251732487	×
2014/3/25 10:16:37	-8.64625	125.5797	-4947472	-726447	地図	2.116517	8447.547	-8.845277611	×	-0.756911	1.278194453	0.1269338	1.29544261	10.01487	5.111379063	×
2014/3/25 10:16:38	-8.64626	125.5797	-4947473	-726449	地図	2.837403	8450.384	-1.20482173	×	0.4529528	1.297607782	-0.163729	1.215908021	9.695666	3.044218651	×
2014/3/25 10:16:39	-8.64627	125.5797	-4947474	-726452	地図	2.748562	8453.133	-4.919729128	×	-0.011609	0.500237899	0.1651049	0.572244174	9.796324	1.863581546	×
2014/3/25 10:17:50	-8.64491	125.576	-4947330	-726858	地図	13.43438	8989.916	-4.666647298	×	-1.016446	1.927463302	0.5508376	1.109630263	9.6202[illegible]8	2.26907215	×
2014/3/25 10:17:51	-8.64483	125.5759	-4947322	-726868	地図	12.23972	9002.155	-4.049699301	×	-0.456577	0.814706838	2.2712195	0.606272777	9.854436	1.033810181	△
2014/3/25 10:17:52	-8.64478	125.5758	-4947316	-726877	地図	11.32933	9013.485	-3.607269735	×	0.1333392	0.484913732	1.5488183	0.46634256	9.8[illegible]6128	0.733553515	△
2014/3/25 10:17:53	-8.64474	125.5757	-4947311	-726888	地図	11.07831	9024.563	-3.31278753	×	0.2999937	0.450682955	1.0889802	0.417589891	9.[illegible]07396	0.636753883	○
2014/3/25 10:17:54	-8.64471	125.5756	-4947309	-726899	地図	11.30262	9035.866	-3.326374079	×	-0.627435	1.114447318	0.9573319	0.52789102	[illegible].766621	0.977294716	△
2014/3/25 10:17:55	-8.6447	125.5755	-4947308	-726910	地図	11.9002	9047.766	-4.863920346	×	-2.324182	1.237769984	-0.032973	1.15665191[illegible]	9.695764	1.000082245	△
2014/3/25 10:17:56	-8.6447	125.5754	-4947308	-726921	地図	10.14366	9057.91	-3.301730849	×	-0.542439	1.638825212	-0.043309	1.2949191[illegible]7	10.00706	1.881297222	×
2014/3/25 10:17:57	-8.6447	125.5754	-4947309	-726929	地図	8.475241	9066.385	-2.651213264	×	0.2008091	0.635157966	0.261093	0.41563[illegible]851	9.703596	1.022599405	△
2014/3/25 10:17:58	-8.64472	125.5753	-4947310	-726937	地図	8.531558	9074.916	-2.255034634	△	0.4695561	0.324666761	0.2638006	0.20[illegible]6029	9.855711	0.518922152	○
2014/3/25 10:17:59	-8.64473	125.5752	-4947312	-726945	地図	7.842529	9082.759	-1.417203017	△	0.7822016	0.239291892	-0.286525	0.27[illegible]712772	9.792846	0.399032415	○

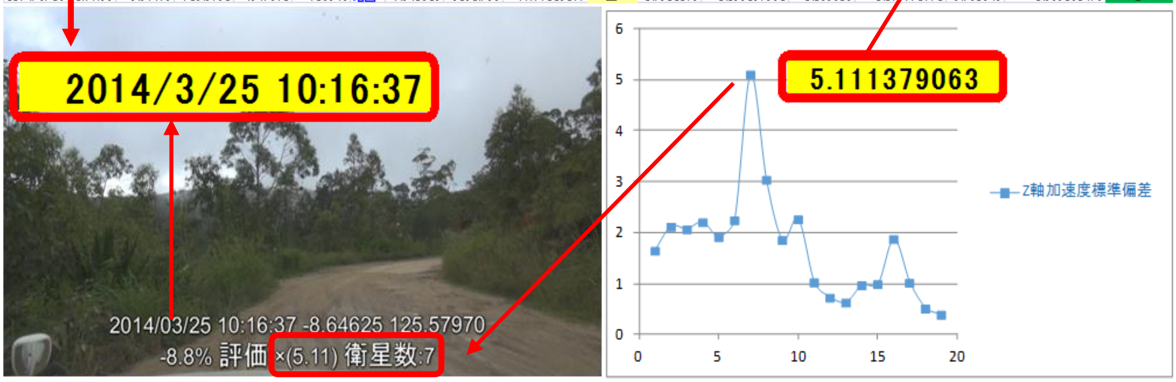


Fig. 15. Evaluation result for BAD Timor-Leste road, obtained using Ippo-Campo

The results of the pavement evaluation conditions in Timor-Leste for both the "GOOD" and "BAD" conditions can be summarized as follows: For the "GOOD" condition roads, the state of the pavement is regarded as being in a "GOOD" condition, as no serious damage is identified. The rate of cracking, the rut depth, and the smoothness are all less than certain values. However, dissimilar results for the evaluation of the "BAD" roads were obtained. It was shown that the road conditions are very poor and actually dangerous, requiring immediate repair work. The damage to this road is not only on the pavement surface, but to the actual road structure also. This situation tends to arise in all Timor-Leste road networks because no rational maintenance work had been carried out. Water overflows and forms puddles on the surface, given the bad state of the road. This applies not only to the surface of the road but also to its entire structure, including the road facilities, such as drainage and walls.

In addition, the condition of the roads in Japan is very different from that existing in Timor-Leste; this can be seen in Figure 16. It can clearly be seen from the results of the evaluation done using Ippo-Campo that 69.4% of the roads are in "GOOD" condition, 22.3% are in "MODERATE" condition, and only 8.3% are in "BAD" condition. It is notable that the maximum value of the standard deviation of the Z-axis acceleration is 0.971.

Therefore, the results of the analysis imply that even roads in Japan's rural areas are of better quality and are better maintained then the main roads in Timor-Leste, as the road construction and maintenance system in Japan involves highly advanced technology and a well-organized association of road managers. Furthermore, the cooperation between the government and university researchers in order to develop maintenance systems for evaluating the condition of the road pavement is well organized.

Fig. 16. Japanese road condition evaluation using Ippo-Campo system

4.3. Use of the System to Analyze Road Pavement Conditions in Timor-Leste

The analysis of the road pavement conditions in Timor-Leste was based on data obtained by the measurements at the location shown in Figure 13. The measurement was divided into four sessions due to the limited budget, as shown in Table 9. The first measurement was conducted from March 25 to 27, 2014 and covered three routes, named route I (No. 1), route II (No. 2) and route III (No. 3). The only route examined in the second measurement was called route IV (No. 4), and was conducted from July 3 to 4, 2014. The third measurement was conducted from March 18 to 20, 2015, and covered two routes, named route V (No. 5) and route VI (No.6). Lastly, the fifth measurement was conducted from May 13 to 17, 2015, and covered three routes, named route VII (No. 7), route VIII (No. 8) and route IX (No. 9).

Table 10 compares the application of both thresholds to all the routes of the Timor-Leste road network. Table 11 lists the results of evaluating the road conditions in Timor-Leste when using the Ippo-Campo system. The measurement produced different data for each route. Route I (No. 1) obtained data for a total of 17,151 points. By using the Japanese threshold, only 0.28% or 48 points were classed as being “GOOD”, 5.14% or 881 points were classed as “MODERATE”, and most of them, at 94.58% or 16,222 points, were “BAD”. This data confirmed that the road pavement is in a very poor condition. Conversely, the results obtained using the Timor-Leste threshold change slightly to 1,563 points, or 9.11%, for the “GOOD” condition while there is a slight increase to 7,021 points, or 40.94%, for the “MODERATE” condition but a significant decrease to 8,567 points, or 49.95%, for the “BAD” condition. As a result, the comparative changes using both thresholds increase considerably to 8.83% for the "GOOD" condition, along with a notable increase for the "MODERATE" condition to 35.80%, while 44.63% represents the greatly decreased "BAD" condition.

The results obtained for Route II (No. 2) show that the road pavement is in a poor condition. From the total of 23,422 items of obtained data, the results using the Japanese threshold shows that 635 points, or 2.71%, are in "GOOD" condition, 3,802, or 16.23%, are in the "MODERATE" condition and 18,985 points, or 81.06%, are in the "BAD" condition. On the other hand, the data using the Timor-Leste threshold changes significantly for each condition. This shows that the "GOOD" condition increased slightly to 5,923 points, or 25.29%, the "MODERATE" condition increased considerably to 6,507 points, or 27.78%, and the "BAD" condition fell significantly to 10,992 points, or 49.95%. As a result, the comparative changes using both thresholds increase noticeably to 22.58% for the "GOOD" condition, and to 11.55% for the "MODERATE" condition, while the "BAD" condition is significantly reduced to 34.13%.

Table 9. MTi-G files and video files for all routes

No	Route number	MTi-G file name (MT_02500197_)	Video file's name	Roundtrip distance (km)
1	I	000-000.txt~015-000.txt	20140325085139.m2ts~20140325152336.m2ts	70×2
2	II	000-000.txt~028-000.txt	20140326081818.m2ts~20140326180224.m2ts	149×2
3	III	000-000.txt~018-000.txt	20140327080907.m2ts~20140327161637.m2ts	122×2
4	IV	017-000.txt~038-000.txt	20140704074541.m2ts~20140704171233.m2ts	67×2
5	V	000-000.txt~020-000.txt	20150318131917.m2ts~20150318202142.m2ts	81×2
6	VI	000-000.txt~009-000.txt	20150319103258.m2ts~20150320094041.m2ts	60.7×2
7	VII	000-000.txt~010-000.txt	20150513093841.m2ts~20150513143347.m2ts	59.6×2
8	VIII	000-000.txt~010-000.txt	20150514101000.m2ts~20150514145816.m2ts	42.5×2
9	IX	011-000.txt~040-000.txt	20150515080826.m2ts~20150516090539.m2ts	88.5×2

Table 10. Comparison using both thresholds for all routes

Route No.	Evaluation results							
	Japanese thresholds				Timor-Leste thresholds			
	GOOD	MODERATE	BAD	Total	GOOD	MODERATE	BAD	Total
I	48	881	16,222	17,151	1,563	7,021	8,567	17,151
II	635	3,802	18,985	23,422	5,923	6,507	10,992	23,422
III	94	1,955	16,743	18,792	3,533	9,324	5,935	18,792
IV	132	2,849	9,384	12,365	4,189	4,664	3,512	12,365
V	1,052	2,372	15,383	18,807	5,130	5,204	8,473	18,807
VI	154	459	12,574	13,187	973	2,705	9,509	13,187
VII	388	1,714	12,785	14,887	2,766	2,679	9,442	14,887
VIII	233	540	11,351	12,124	1,156	2,727	8,241	12,124
IX	394	426	18,846	19,666	1,221	3,611	14,834	19,666

Table 11. Evaluation result of road condition in Timor-Leste using Ippo-Campo system

Route No.	Percentages of each conditions (%) (Japanese thresholds)				Percentages of each conditions (%) (Timor-Leste thresholds)				Comparative changes using both thresholds (%)		
	GOOD	MODE RATE	BAD	Tot al	GOOD	MODE RATE	BAD	Tot al	GOO D	MODE RATE	BAD
I	0.28	5.14	94.58	100	9.11	40.94	49.95	100	8.83	35.80	-44.63
II	2.71	16.23	81.06	100	25.29	27.78	46.93	100	22.58	11.55	-34.13
III	0.50	10.40	89.10	100	18.80	49.62	31.58	100	18.30	39.21	-57.51
IV	1.07	23.04	75.89	100	33.88	37.72	28.40	100	32.81	14.68	-47.49
V	5.59	12.61	81.79	100	27.28	27.67	45.05	100	21.68	15.06	-36.74
VI	1.17	3.48	95.35	100	7.38	20.51	72.11	100	6.21	17.03	-23.24
VII	2.61	11.51	85.88	100	18.58	18.00	63.42	100	15.97	6.48	-22.46
VIII	1.92	4.45	93.62	100	9.53	22.49	67.97	100	7.61	18.04	-25.65
IX	2.00	2.17	95.83	100	6.21	18.36	75.43	100	4.20	16.20	-20.40

For route III (No. 3), the result obtained using the Japanese thresholds shows that the road pavement surface is in a BAD condition. This was confirmed by the total evaluation result for the total obtained data. The obtained consisted of a total of 18,792 points divided into three conditions, specifically, 94 points, or 0.50%, corresponding to the “GOOD” condition, 1,955 points, or 10.40%, corresponding to the “MODERATE” condition, and about 16,743 points, or 89.10%, corresponding to the “BAD” condition. Conversely, the result using the Timor-Leste threshold exhibits a significantly high value for each condition. In particular, the “GOOD” condition increased to 3,533 points, or 18.30%, the “MODERATE” condition increased to 9,324 points, or 49.62%, while the “BAD” condition fell to 31.58%.

As a result, the comparative changes using both thresholds increased noticeably to 18.30% for the “GOOD” condition, and to 39.21% for “MODERATE” condition, but fell significantly to 57.51% for the “BAD” condition.

For route IV (No. 4), the result obtained using the Japanese threshold shows that the road pavement surface corresponds to the “BAD” condition. This measurement obtained a total of 12,236 data points: 132 points, or 1.07%, for the “GOOD” condition, 2,849 points, or 23.04%, for the “MODERATE” condition and 9,384 points, or 75.89%, for the “BAD” condition. However, the results obtained using the Timor-Leste threshold resulted in a significant value for each condition: 4,189 points, or 33.88% for the “GOOD” condition and 4,664 points, or 37.72%, for the “MODERATE” condition, while the “BAD” condition fell to 3,512 points, or 28.40%. As a result, comparative changes using both thresholds increase considerably to 32.81%, with the “MODERATE” condition increasing considerably to 14.68%, while there is a significant drop to 47.49% for the “BAD” condition.

For route V (No. 5), the result obtained using the Japanese threshold shows that the road pavement surface is in a poor condition. This measurement obtained a total of 18,807 data points: 1,052 points, or 5.59%, for the “GOOD” condition, 2,372 points, or 12.61%, for the “MODERATE” condition and 15,383 points, or 81.89%, for the “BAD” condition. However, the result obtained using the Timor-Leste threshold exhibited a significantly high value for each condition: 5,130 points or 27.28% of this road can be classed as “GOOD”, and 5,204 points, or 27.62%, as “MODERATE”, while those which can be classed as “BAD” fell to 8,473 points, or 45.05%. As a result, the comparative changes using both thresholds increased considerably to 21.68% for the “GOOD” condition, the “MODERATE” condition increases notably to 15.06%, while the “BAD” condition falls significantly to 36.74%.

For route VI (No. 6), the result obtained using the Japanese threshold shows that the road pavement surface is in a BAD condition. This measurement obtained a total of 13,187 data points: 154 points, or 1.17%, for the “GOOD” condition, 459 points, or 3.48%, for the “MODERATE” condition, and 12,574 points, or 95.35%, for the “BAD” condition. Conversely, the results obtained using the Timor-Leste threshold resulted in a significantly high value for each condition: the results showed that 973 points, or 7.38%, for this road are “GOOD”, 2,705 points, or 20.51%, are “MODERATE”, while the number of “BAD” points falls to 9,509 points, or 72.11%. As a result, the comparative changes using both thresholds increase slightly to 6.21% for the “GOOD” condition, the “MODERATE” condition increases considerably to 17.03%, while the “BAD” condition falls significantly to 23.24%.

For route VII (No. 7), the result obtained using the Japanese threshold shows that the road pavement surface is in a poor condition. This measurement produced a total of 14,887 data points: 388 points, or 2.61%, for the “GOOD” condition, 1,714 points, or 11.51%, for the “MODERATE” condition, and 12,785 points, or 85.88%, for the “BAD” condition. Conversely, the result obtained using the Timor-Leste threshold resulted in a significant value for each condition. It showed a considerable increase to 2,766 points, or 18.58%, for the “GOOD” condition and 2,705 points, or 18%, for the “MODERATE” condition, while the number of points corresponding to the “BAD” fell to 9,509 points, or 63.42%. As a result, the comparative changes using both thresholds increased noticeably to 15.97% for the “GOOD” condition, the “MODERATE” condition increased slightly to 6.48% while the “BAD” condition fell considerably to 22.46%.

For route VIII (No. 8), the result obtained using the Japanese threshold shows that the road pavement surface is in a BAD condition. This measurement obtained a total of 12,124 data points: 233 points, or 1.92%, for the “GOOD” condition, 540 points, or 4.45%, for the “MODERATE” condition and 11,351 points, or 93.62%, for the “BAD” condition. However, the results obtained using the Timor-Leste threshold exhibited a significantly high value for each condition: 1,156 points, or 9.53%, on this road are “GOOD”, 2,727 points, or 22.49%, are “MODERATE”, while the “BAD” condition fell to 8,241 points, or 67.97%. As a result, the comparative changes using both thresholds increase slightly to 7.61% for the “GOOD” condition, while the “MODERATE” condition increased noticeably to 18.04%, and fell significantly to 25.65% for the “BAD” condition.

For route IX (No. 9), the result obtained using the Japanese threshold shows that the road pavement surface is in a poor condition. This measurement produced a total of 19,666 data points: 394 points, or 2%, for the “GOOD” condition, 426 points, or 2.17%, for the “MODERATE” condition and 18,846 points, or 95.83%, for the “BAD” condition. Conversely, the result obtained using the Timor-Leste threshold resulted in a significant value for each condition. In this case, there was a slight increase to 1,221 points, or 6.21%, that were “GOOD” and 3,611 points, or 18.36%, that were “MODERATE”, while the “BAD” condition fell to 14,834 points, or 75.43%. As a result, the comparative changes using both thresholds increased slightly to 4.2% for the “GOOD” condition, while the “MODERATE” condition increased considerably to 16.20%, and the “BAD” condition fell noticeably to 20.40%.

5. Road Maintenance Decision-Making Based on Comprehensive Evaluation by AHP Model

5.1. Application of AHP to Video Data from Timor-Leste Road Networks

The analytic hierarchy process (AHP) is an effective tool for dealing with complex decision-making, and may help the decision maker to set priorities and make the best decision (Saaty, 1980; Behbahani et al., 2014). The AHP method is used to derive a ratio scale from paired comparisons. It also allows for some small inconsistencies in judgments.

The government of the Democratic Republic of Timor-Leste intends to rehabilitate or upgrade the national road networks in accordance with the development priorities of the National Strategic Development Plan. However, there are some problems due to budget limitations, the lack of well-organized engineers etc. Therefore, there is a need for an effective means of prioritization (Taherkhani and Tajdini, 2020). Figure 17 shows the comprehensive evaluation of video files from the Ippo-Campo system using the AHP to prioritize the attributes of roads in need of maintenance and improve the Timor-Leste road networks.

The goal is to prioritize the road attributes for maintenance and improvement work on Timor-Leste road networks. The selected criteria are strength, durability, safety, workability and maintenance, as shown in Figure 17. The alternatives are retaining walls, drainage, culverts, debris and landslide removal, and tree and grass cutting (see Figure 17). In addition, these criteria and alternatives are used to form a comparison matrix for computing the normalized principal eigenvector, as shown in Table 12. The results can be seen in the following tables.

Table 12 shows the pairwise comparisons of the criteria. The scale ranged from 7 to 1/7 and was composed of criteria and five comparisons. The consistency ratio was smaller than 10%. Therefore, the given comparison numbers are acceptable. The weights for each criterion were found to be: strength 43.63%, durability 13.52%, safety 7.59%, workability 5.69% and maintenance 29.57%. Consequently, it can be assumed that the most important criterion as identified by the pairwise comparison of the criteria is strength, followed by maintenance, durability, safety and workability, as shown in Figure 18.

Tables 13-17 summarize the results of the pairwise comparison of the alternatives for each criteria. The comparison used a scale ranging from 9 to 1/9. The comparisons were computed by arranging the judgment values in the matrix. In this case, five comparisons were needed based on the number of criteria. The weighting values for each criterion were labelled strength, durability, safety, workability and maintenance. Based on the results, the alternatives were dominated by retaining wall followed by drainage, tree and grass cutting, debris and landslide removal, and culverts, as shown in Figure 19.

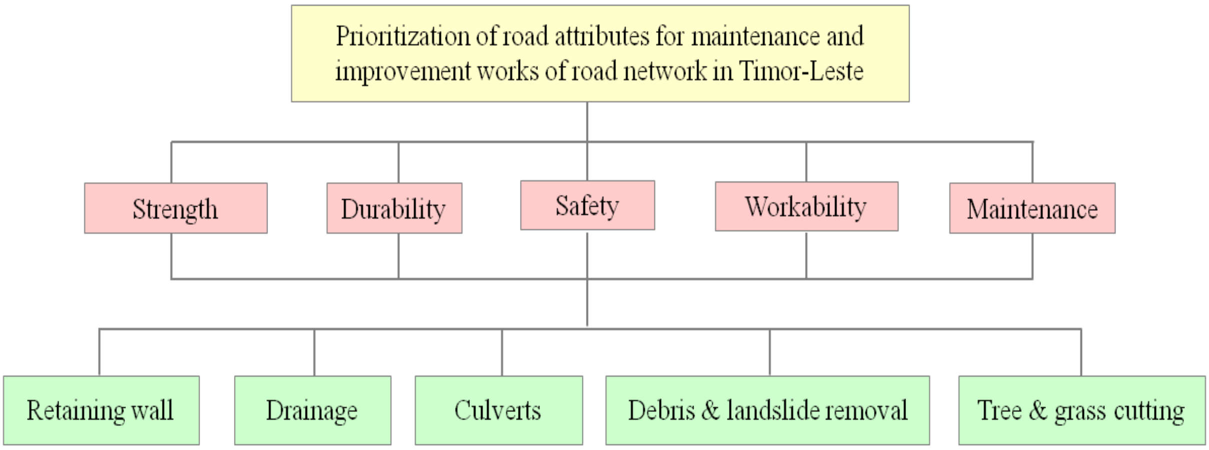


Fig. 17. AHP of Timor-Leste road networks

Table 12. Pairwise comparisons among criteria

L29D17:L28D17:L26	**Strength**	**Durability**	**Safety**	**Workability**	**Maintenance**	**Geometric mean**	**Normalized**	**Weight**
Strength	1	3	5	7	2	2.914	0.4363	0.4363
Durability	1/3	1	3	3	1/5	0.903	0.1352	0.1352
Safety	1/5	1/3	1	2	1/4	0.506	0.0759	0.0759
Workability	1/7	1/3	1/2	1	1/3	0.380	0.0569	0.0569
Maintenance	1/2	5	4	3	1	1.974	0.2957	0.2957
Sum	**2.18**	**9.67**	**13.50**	**16.00**	**3.78**	**6.68**	**1.00**	**1.00**
						Lambda (λ)-max	5.3100	
						CI	0.0775	
						CR	0.0692	< 10%

Table 13. Pairwise comparison of alternatives (strength)

	Retaining wall	Drainage	Culverts	Debris and land slide removal	Tree and grass cutting	Geometric mean	Normalized	Weight
Retaining wall	1	2	3	7	4	2.787	0.4814	0.4814
Drainage	1/2	1	4	1/4	1/3	0.699	0.1207	0.1207
Culverts	1/3	1/4	1	1/5	1/2	0.384	0.0663	0.0663
Debris and land slide removal	1/7	1/4	5	1	1/3	0.569	0.0983	0.0983
Tree and grass cutting	1/4	3	2	3	1	1.351	0.2334	0.2334
Sum	**2.23**	**6.50**	**15.00**	**11.45**	**6.17**	**5.79**	**1.00**	**1.00**
						Lambda(λ)-max	5.4150	
						CI	0.1037	
						CR	0.0926	< 10%

Table 14. Pairwise comparison of alternatives (durability)

	Retaining wall	Drainage	Culverts	Debris and land slide removal	Tree and grass cutting	Geometric mean	Normalized	Weight
Retaining wall	1	2	3	6	4	2.702	0.4034	0.4034
Drainage	1/3	1	6	6	6	2.352	0.3512	0.3512
Culverts	1/5	1/6	1	3	4	0.833	0.1243	0.1243
Debris and land slide removal	1/6	1/6	1/3	1	3	0.488	0.0729	0.0729
Tree and grass cutting	1/4	1/6	1/4	1/3	1	0.322	0.0481	0.0481
Sum	**1.95**	**3.50**	**10.58**	**16.33**	**18.00**	**6.70**	**1.00**	**1.00**
						Lambda (λ)-max	5.3886	
						CI	0.0972	
						CR	0.0867	< 10%

Table 15. Pairwise comparison of alternatives (safety)

	Retaining wall	Drainage	Culverts	Debris and land slide removal	Tree and grass cutting	Geometric mean	Normalized	Weight
Retaining wall	1	2	3	1/2	1/5	0.903	0.1348	0.1348
Drainage	1/2	1	2	1/4	1/4	0.574	0.0857	0.0857
Culverts	1/3	1/2	1	1/6	1/6	0.341	0.0509	0.0509
Debris and land slide removal	2	4	6	1	1/2	1.888	0.2818	0.2818
Tree and grass cutting	5	4	6	2	1	2.993	0.4467	0.4467
Sum	**8.83**	**11.50**	**18.00**	**3.92**	**2.12**	**6.70**	**1.00**	**1.00**
						Lambda (λ)-max	5.1428	
						CI	0.0357	
						CR	0.0319	< 10%

Table 16. Pairwise comparison of alternatives (workability)

	Retaining wall	Drainage	Culverts	Debris and land slide removal	Tree and grass cutting	Geometric mean	Normalized	Weight
Retaining wall	1	3	5	7	9	3.936	0.5338	0.5338
Drainage	1/3	1	2	5	5	1.755	0.2381	0.2381
Culverts	1/5	1/3	1	3	3	0.903	0.1224	0.1224
Debris and land slide removal	1/7	1/5	1/3	1	2	0.453	0.0614	0.0614
Tree and grass cutting	1/9	1/5	1/3	1/2	1	0.326	0.0443	0.0443
Sum	**1.79**	**4.73**	**8.67**	**16.50**	**20.00**	**7.37**	**1.00**	**1.00**
						Lambda (λ)-max	5.0407	
						CI	0.0102	
						CR	0.0091	< 10%

Table 17. Pairwise comparison of alternatives (maintenance)

	Retaining wall	Drainage	Culverts	Debris and land slide removal	Tree and grass cutting	Geometric mean	Normalized	Weight
Retaining wall	1	2	3	2	3	2.048	0.3428	0.3428
Drainage	1/2	1	3	4	5	1.974	0.3305	0.3305
Culverts	1/3	1/3	1	2	2	0.850	0.1424	0.1424
Debris and land slide removal	1/3	1/4	1/2	1	3	0.660	0.1105	0.1105
Tree and grass cutting	1/2	1/5	1/2	1/3	1	0.441	0.0738	0.0738
Sum	**2.67**	**3.78**	**8.00**	**9.33**	**14.00**	**5.97**	**1.00**	**1.00**
						Lambda (λ)-max	5.3680	
						CI	0.0920	
						CR	0.0821	< 10%

5.3. Analysis of Results and Discussions

The application of AHP to Timor-Leste road networks was conducted to study multi-criteria decision-making, particularly the prioritization of work with a limited budget. The comprehensive evaluation of Timor-Leste road network used five criteria: strength, durability, safety, workability and maintenance. However, the alternatives included retaining walls, drainage, culverts, debris and landslide removal and tree and grass cutting. The results of the comparisons were arranged in a matrix using the comparison ranging scale. The weighting percentages were obtained by computing the normalized principal eigenvector. The consistency ratio was checked in order to confirm that the complete results were consistent (CR < 10%). For example, in this case, the subjective evaluation for the Timor-Leste road networks was consistent. Therefore, the analysis of the road attributes in need of maintenance and improvement work resulted in the most preferred alternative of retaining wall with a 38.31% weighting, followed by drainage at 21.79%, tree and grass cutting at 16.66%, debris and landslide removal at 11.03%, and culverts at 9.87%, as shown in both Table 18 and Figure 20. According to these results, the application of the AHP method using the video file obtained from Ippo-Campo will help road administrators to establish rational strategies for both maintenance and improvement of the road networks in Timor-Leste. In this study, the preferred target routes were defined by comparing the pairwise comparison among alternatives for each route. As a result, the most important route that gives an economic improvement to the development of Timor-Leste was identified as route III (No. 3), followed by route II (No. 2), route I (No. 1), route VII (No. 7), route V (No. 5), route IX (No. 9), route VI (No. 6), route IV (No. 4) and finally route VIII (No. 8).

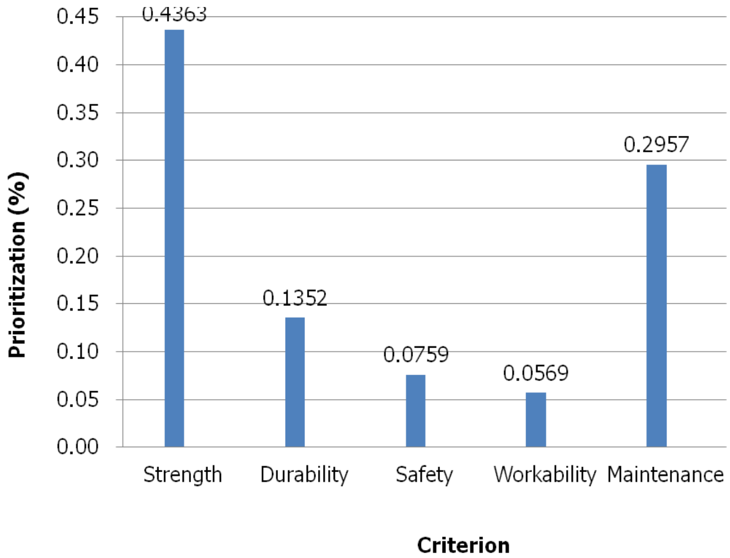


Fig. 18. Pairwise comparison of criteria

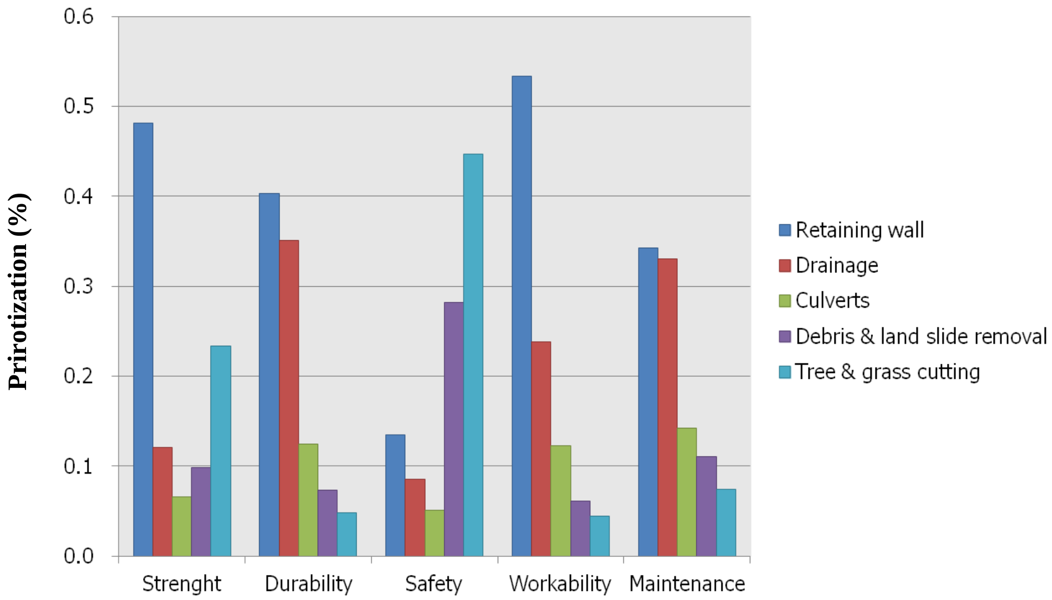


Fig. 19. Pairwise comparisons of alternatives

Table 18. Comprehensive evaluation of road attributes for Timor-Leste road networks

	Strength	**Durability**	**Safety**	**Workability**	**Maintenance**	**Comprehensive evaluation**
Retaining wall	0.4814	0.4034	0.1348	0.5338	0.3428	0.3831
Drainage	0.1207	0.3512	0.0857	0.2381	0.3305	0.2179
Culverts	0.0663	0.1243	0.0509	0.1224	0.1424	0.0987
Debris and land slide removal	0.0983	0.0729	0.2818	0.0614	0.1105	0.1103
Tree and grass cutting	0.2334	0.0481	0.4467	0.0443	0.0738	0.1666
Sum	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

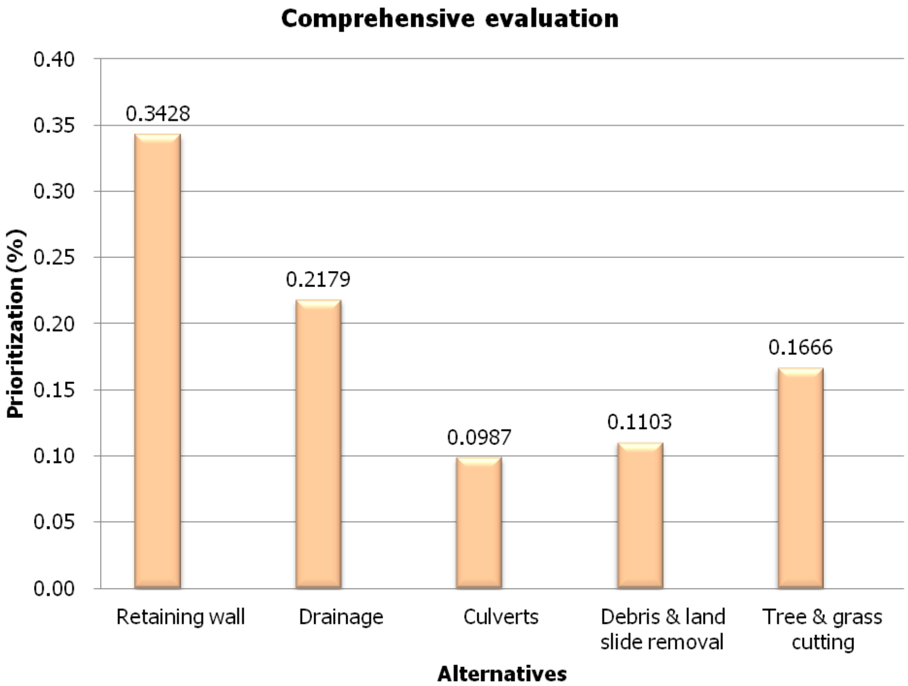


Fig. 20. Analysis result of comprehensive evaluation of road attributes

6. Conclusions

The Ippo-Campo system is a low-cost IT-based road condition assessment system that has been developed based on digital video, vehicle vibrations, audio and GPS data. Initially, this system was designed for Japan's roads, where it has become established as a suitable IT-based system. Because the system is IT-based, it can easily obtain output data in various formats that are both effective and efficient. In addition, the AHP method for multi-decision-making can be considered to prioritize a decision related to the required work according to the urgency of the need. Therefore, both the Ippo-Campo system and the AHP method can be applied in other countries. In developing countries, there are some problems related to road maintenance because there are budget limitations for maintaining the road networks. This issue results in many roads remaining damaged, and is affected by the economic status of the country. Hence, the use of this system in a developing country is advantageous because it is a relatively low-cost system. The application of the system and the AHP method to a road network in Timor-Leste confirmed the effectiveness and workability of the system.

The main conclusions obtained in this study can be summarized as follows:

- A low-cost IT-based road condition assessment system ("Ippo-Campo") developed based on digital video, vehicle vibrations, audio and GPS data can be applied to Timor-Leste's road network with a different threshold.
- The proposed system was applied to actual road networks (target routes) in both Mine City in Yamaguchi Pref., Japan and Timor-Leste to evaluate its effectiveness. As a result, the system will allow a rational maintenance strategy for repairs works to be established based on the condition assessment.
- Timor-Leste, as a developing country, needs a simple and rational system to assess the condition of its roads and prioritize their maintenance. Therefore, the Ippo-Campo system and the AHP method can contribute to make a maintenance strategy for Timor-Leste's road network in the future.
- The application of the AHP method to the Timor-Leste road maintenance strategy will effectively support

decision-making with regard to complex sustainability issues and can help to recognize and define problems in detail.
- The AHP helps to capture subjective and objective evaluation measures in the Timor-Leste road maintenance strategy, while providing a useful mechanism for checking the consistency of the evaluation measures and alternatives and thus reduce bias in decision-making.

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