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Determination of the Critical Indicators of Road Performance for Disaster Evacuation Route in the Coastal Area, Padang City, Indonesia

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Abstract **-** It is the time for road infrastructure management system to switch the perspective of life plan-based management to another approach which is more efficient in terms of budgeting and can optimize road performance. The use of performance indicators has been recommended for this. This study aims to formulate the performance indicators for Performance Based Contracting (PBC) method widely used now now. These performance indicators are formulated for West Sumatera Province, designated as disaster zones. The integration of the three qualitative methods, namely the Delphi method, AHP and method of Natural Cut-off Point has succeeded in formulating indicators. Delphi method is used to identify indicators, while the AHP is used to prioritize the indicators and the last, the method of Natural Cut-off Point is used to select the critical indicators. A total of six critical indicators are identified, namely damage at the end of pavement, drainage, culverts, Potholes, width of pavement and cracking.

***Keywords*:** Indicators, road performance, critical, disaster and coastal area.

1. Introduction

West Sumatera is one of the provinces in Indonesia with coastal areas consisting of about 100 islands, about 1,400 kms of coastline and 20,000 kms^2 of territorial waters. The exclusive economic zone of West Sumatera is approximately 140,000 kms^2 and thousands of fishermen operating in the area (Kunzman, 2002). As part of a region located in Circum Pacific, West Sumatera is faced with the threat of devastating magnitude tectonic earthquake, Mentawai Megathrust. There is a high probability of occurrence of large earthquakes along the subduction of megathrust beneath the Mentawai islands in the near future (Li et al., 2012). Giant tsunami as a result of the earthquake off the west coast of Sumatera on December 26, 2004 had raised a number of pressing issues regarding the tsunami. In particular, this incident shows that knowledge of the tsunami and its potential impact is very slight, and also that Indonesia and international community do not have a clear strategy on how to deal with this terrible event (Tinti et al., 2005). Subsequent tectonic earthquake with significant impact occurred on 30 September 2009. Though, the disaster did not cause a tsunami, the earthquake had damaged a number of physical infrastructure, including roads. In Padang City (capital city of West Sumatera), it was noted that as many as 168 road segments suffered severe damage, 65 segments were moderate damage and 26 segments suffered slightly damage (Kamil et al., 2013).

Since then, Padang City authority has been continuously putting in the efforts to increase vigilance in order to deal with the disasters. One of the efforts made is by widening the Pasar Alai By-Pass road as the disaster evacuation line (Listyawati and Sulastriyono, 2014). As it is known, Padang City has been indicated as one of the potential areas to be affected by tsunami, in the near future (Borrero et al., 2006; McCloskey et al., 2010). The road authority of Padang City allocated an amount of 400 billion Rupiah, which was an estimate based on the scale of the disaster. Thereafter, the budget allocated by the government for road maintenance is based on the usual life plan maintenance.

Poor budget estimation for maintenance of infrastructure assets (including roads) is an important issue that is much discussed today (Piyatrapoomi et al., 2004). Life plan-based road infrastructure management is considered ineffective because it does not take into account of the road performance thus potentially on the emergence of various problems in different conditions (Kamil et al., 2013). Maintenance planning as part of the road infrastructure management does not necessarily correspond with the actual conditions at the implementation time. Budget availability is usually not sufficient to guarantee the road performance, has always been at a level that assures long life of the plan (Bako et al., 2005).

Several previous studies have proposed various approaches as another perspective in the road infrastructure management in disaster-prone areas, in particular on road performance. Kamil et al. (2012a) has developed a database model based on web-GIS application to monitor the road performance in West Sumatera. Several other studies have formulated strategies and policies in road maintenance system in Padang City and West Sumatera (Kamil et al., 2012b; Kamil et al., 2012c; Kamil et al., 2012d). Previous studies have also developed key performance indicators (KPIs) for road maintenance management systems in various countries (Fedojuk et al., 2009; PAG, 2006; Haas et al., 2009; Horak et al., 2001).

This study aims to identify and develop performance indicators in order to optimize the road infrastructure performance in West Sumatera as a disaster zone. A benchmarking study against previous studies that have used road performance indicators in the phase of construction and maintenance methods called Performance Based Contracts (PBC) (Haryanti 2007; Tamin et al., 2009; Zietlow, 2004; Transportation Research Board (TRB), 2009; Stankevich et al., 2005; Berkland and Bell, 2007; Queiroz, 2007; Panthi, 2009; Kashiwagi et al., 2003), was performed. Based on these studies, indicators that are considered as critical, were identified through a simple elimination method. These critical indicators are recommended to be managed optimally for the road infrastructure in West Sumatera in the framework of disaster mitigation, preparedness, especially to the possibility of earthquake and tsunami.

2. Previous Studies

A benchmarking study against previous studies conducted to identify the performance indicators of the PBC method. This is an innovative contracts method different from the traditional contract system that based on life design and budgeting. PBC are considered to overcome the poor quality of roads by controlling the road performances (Kamil et al., 2013). Table 1 shows the performance indicators for the PBC method that has been used in previous research.

Table 1. Road Performance Indicators used in Previous Studies

No.	Indicators	Previous Studies
1	Width of hardening	Haryanti (2007)
2	Potholes	Haryanti (2007), Tamin *et al.* (2009), Zietlow (2004), Kashiwagi *et al.* (2003), TRB (2009), Stankevich *et al.* (2005), Queiroz (2007)
3	Cracking	Haryanti (2007), Zietlow (2004), Kashiwagi *et al.* (2003), Stankevich *et al.* (2005), Berkland and Bell (2007), Queiroz (2007), Panthi (2009)
4	Surface roughness	Haryanti (2007), Tamin *et al.* (2009), Zietlow (2004), Kashiwagi *et al.* (2003), TRB (2009), Queiroz (2007), Panthi
5	Deflection	Haryanti (2007), Tamin *et al.* (2009), Panthi (2009)
6	Damage in the end of pavement	Haryanti (2007), Stankevich *et al.* (2005), Berkland and Bell (2007)
7	Road buffer	Haryanti (2007), Zietlow (2004), Queiroz (2007)
8	Drainage	Haryanti (2007), Tamin *et al.* (2009), Zietlow (2004), Stankevich *et al.* (2005), Queiroz (2007)
9	Water channel	Haryanti (2007), Tamin *et al.* (2009), Stankevich *et al.* (2005)
10	Traffic signs	Haryanti (2007), Tamin *et al.* (2009), Zietlow (2004), Stankevich *et al.* (2005), Berkland and Bell (2007)
11	Guardrail	Haryanti (2007), Tamin *et al.* (2009), TRB (2009), Stankevich *et al.* (2005), Berkland and Bell (2007)
12	Vehice speed	Tamin *et al.*, (2009)
13	The height of plant/grass	Zietlow (2004), TRB (2009), Stankevich *et al.* (2005), Berkland and Bell (2007), Queiroz (2007)
14	Trees covering the road	Berkland and Bell (2007)
15	Foreign elements	Zietlow (2004), Stankevich *et al.* (2005), Queiroz (2007)
16	Pile of snow	TRB (2009)
17	Billboard	Stankevich *et al.* (2005)
18	Road marks	Haryanti (2007), Stankevich *et al.* (2005), Berkland and Bell (2007)
19	Plotting	Zietlow (2004), Kashiwagi *et al.* (2003), TRB (2009), Queiroz (2007)
20	Asphalt thickness	Zietlow (2004)

3. Results and Discussion

3.1. The Formulation of Road Performance Indicators Using Delphi Method

A total of three rounds of Delphi was conducted to identify road performance indicators in accordance with local conditions of West Sumatera as the disaster zone. Delphi method is used because of its ability to collect data based on the ability and experience of the respondents (Hsu and Stanford 2007) and can reach an agreement based on respondents' opinions about the topics discussed (Dalkey and Helmer, 1963; Dalkey, 1969; Linstone and Turoff, 1975; Lindeman, 1981; Martino, 1983; Young and Jamieson, 2001).

The participants in the three-round Delphi numbering five people who are experts in the field of road infrastructure in West Sumatera representing government, academia and professionals (consultants and contractors). They were asked for their opinions and views on the importance of performance indicators that have been formulated using questionnaires. A five-point Likert scale with different interests scale used in the questionnaire. In the first round of Delphi, as many as 8 (eight) road performance indicators eliminated from 20 (twenty) indicators based on an assessment of respondents. Meanwhile, 3 (three) new indicators were added, so the first round Delphi produces 15 (fifteen) road performance indicators.

In the second round of Delphi, as many as 3 (three) road performance indicators of the 15 (fifteen) indicators are eliminated based on the assessment of the respondents, so the second round Delphi produces 12 (twelve) indicators. The third round of Delphi then generates a consensus reaching an agreement from the respondents that the 12 (twelve) performance indicators are considered valid and in accordance with the local conditions of West Sumatera. These performance indicators are grouped into three criteria, namely the road surface, road supports and road facilities. Figure 1 shows the performance indicators that have been validated through three rounds of Delphi.

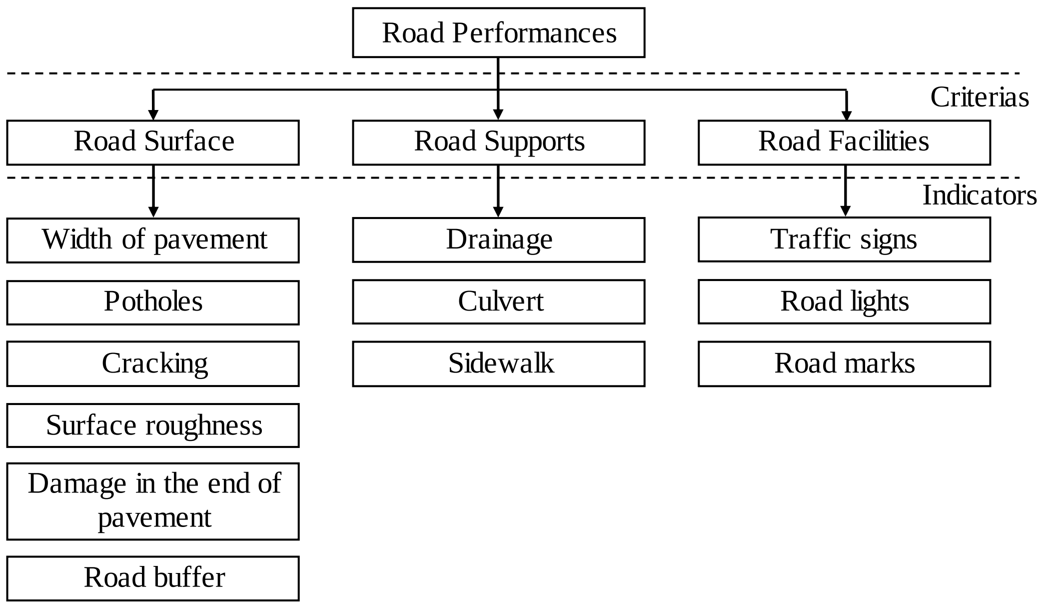

Figure 1. Road Performance Indicators of West Sumatera

Figure 1 shows that there are 12 (twelve) performance indicators for road infrastructure in West Sumatera. Sidewalk and road lights are two additional indicators of the respondents' expert on the stage of the three-round Delphi. The indicators incorporated in the criteria of the road surface are physical structure indicators of the road, while the indicator incorporated in the road supports and road facilities criteria are non-structural indicators. Based on the Delphi method, the 12 (twelve) indicators are deemed appropriate to measure and assess the road infrastructure performance in West Sumatera for the PBC method.

3.2. The Critical Road Performance Indicators for West Sumatera

The twelve performance indicators that have been formulated then are prioritized by the Analytical Hierarchy Process (AHP). This prioritization aims to determine the weight of each indicator based on the importance rate of its use. This is important because, in principle, not all indicators can be used optimally so that the indicators need to be identified based on the weight of the importance. A survey was conducted by involving the same respondents at the stage of Delphi, where they were asked for an assessment of the relative importance of each indicator. Table 2 displays the results of the indicators assessment using AHP method.

Table 2. Indicators Assessment using AHP Method

Criterias	Weight of Criterias	Indicators	Weight of Indicators	Main Weight of Indicators	Maximum Assesment	Value
Road Surface	0.55	Width of pavement	0.17	0.0931	100	9.31
		Potholes	0.18	0.0997	100	9.97
		Cracking	0.16	0.0891	100	8.91
		Surface roughness	0.10	0.0517	100	5.17
		Damage at the end of pavement	0.22	0.1173	100	11.73
		Road buffer	0.14	0.0783	100	7.83
Road Supports	0.25	Drainage	0.41	0.1034	100	10.34
		Culvert	0.41	0.1034	100	10.34
		Sidewalk	0.17	0.0422	100	4.22
Road Facilities	0.20	Road signs	0.33	0.0651	100	6.51
		Road marks	0.27	0.0531	100	5.31
		Road lights	0.33	0.0651	100	6.51
Total Value of Road Performance						96,14

Table 2 shows that the criteria of the road surface have the largest combined weight value (0.54) influenced by the amount of the six indicators incorporated in these criteria. The main weight of the indicator is the result of multiplying the weight of indicators and weight of criterias, then the main weight is multiplied with the maximum assessment value of indicators (100) in order to obtain the value of each indicator. The value of each indicator is then prioritized and shown in Table 3.

Tabel 3. The Priority of Indicators based-on the Value

Indicators	Value
Damage at the end of pavement	11.73
Drainage	10.34
Culverts	10.34
Potholes	9.97
Width of pavement	9.31
Cracking	8.91
Road buffer	7.83
Road signs	6.51
Road lights	6.51
Road marks	5.31
Surface roughness	5.17
Sidewalk	4.22

Table 3 shows that the indicator of damage at the end of pavement has the greatest weight (11.73), while the indicator of sidewalk has a smallest weight (4.22). The indicators of damage at the end of pavement has the greatest value because the pavement is very important for the treatment of physical roads. Several previous studies have shown that the type and model of pavement greatly affect the quality of the roads that will have an impact on the sustainability of the road, smooth traffic and accidents (Kamil et al., 2015). Ullas et al. (2013) suggested that damage of pavement is a complex problem involving not only a reduction in the structural quality but also have an impact on the functional problems. Sidewalk, despite having the smallest value based on the assessment, but it remains to be an important indicator in measuring and assessing the road performances. Sidewalk is an important part of the urban traffic system, where the quality of service will affect the mobilization of citizens (Dandan et al., 2007). The absence of sidewalk that is well constructed and maintained will limit the mobility of people with diverse types of limitations (Ferreira and Sanchez, 2007). In a broader context, sidewalk has become an important part of transportation planning that have diverse effects for economic development, recreation and environmental improvements (Ehrenfeucht and Sideris, 2010).

A simple process of elimination is made to select indicators that are considered critical. This method, called method of Natural Cut-off Point (Kamil et al., 2014; Tam and Tummala, 2001), is used to determine the cut-off value of the indicator. The indicators with values that are below the cut-off value will be eliminated, while the indicator with values above the cut-off value is identified as critical indicator. Based on Table 3, the highest value is 11.73 and the lowest value is 4.22, so that the cut-off value determined by the following calculation:

cut-off point = (average highest score + average lowest score) / 2
= (11.73 + 4.22) / 2
= 7.98

Based on this calculation, there are only six indicators deemed as critical, namely, damage at the end of pavement (11.73), drainage (10.34), culverts (10.34), potholes (9.97), width of pavement (9.31) and cracking (8.91). Thus, all of these six indicators are considered important and crucial in achieving optimal road performance in West Sumatera.

4. Conclusion

This study has been able to formulate critical performance indicators for the road infrastructure performance management system in West Sumatra. A benchmarking study against previous studies has formulated some road performance indicators used in the PBC method. The integration of the three qualitative methods, namely the Delphi, AHP and Natural Cut-off Point methods have succeeded in formulating indicators. The Delphi method is used to identify the indicators, while the AHP is used to prioritize the indicators and the last, the Natural Cut-off Point is used to select the critical indicators. A total of six critical indicators are identified, namely damage at the end of pavement, drainage, culverts, potholes, width of pavement, and cracking, which can be recommended as a guideline for the realization of the optimal road performance management system in West Sumatera in the framework of disaster mitigation.

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