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Effectiveness Evaluation of Pavement Maintenance and Rehabilitation Works of Toll Highway

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Abstract **Original Research Article**

A pavement's main role is to serve as a comfortable and safe riding surface for road users. Unfortunately, contractors often face a severe issue which is pavement distress. Pavement rehabilitation is a significant and improvable process, which regulates the road network's function and is negatively impacted by deterioration. Considering the fact that pavement's rehabilitation is a continuous and significant activity, there should be effective maintenance to prevent repeated and recurrent works. As such, in order to meet the goals of the pavement, this research aims to highlight the pavement defects' sources and assess the effectiveness of pavement rehabilitation and maintenance efforts in terms of cost, time and quality within the Semarang Toll Highway district of Indonesia. Data collection involves collecting information from the bill of quantity, operation reports, contract documents and consultant reports. Following this, the information and presented and assess based on this study's aim and objectives. In conclusion, some distress sources are identified to enhance the effectiveness of pavement rehabilitation and maintenance efforts within Semarang Highway.

Keywords: Stormwater drainage, Pavement maintenance, Pavement defects, Drainage infrastructure.

INTRODUCTION

Globally, flexible pavement is utilized at all networks of federal roads, highways, local roads, expressways and others. Following successful construction of pavement, it is important to carry out pavement preventive maintenance that focuses on maintain roads in good condition via early maintenance treatment. [1,2]. One of the key challenges was faced by highway agencies today is the ability to maintain the quality of the existing pavements. Among the nearly 693 kilometers of Toll Highway systems in Indonesia up to 2010, about 40% of the Regional Toll Highway and 60 % of the Urban Toll Highway kilometers are rated in very good to good condition based on AASHO Road Test (PT. Jasa Marga (JM)), a general directorate of highways engineering). The placement of a rehabilitative treatment on any pavement too late or too early is not cost-effective [3].

All efforts are carried out by pavement maintenance and rehabilitation in minor and major scales for the provision and maintenance of serviceable roadways. The building of roads an highway necessitates a large amount of capital or financial investment [4]. Some highways in Indonesia have been set up by both private and state owned companies namely Jakarta urban toll road, Semarang urban toll road, Jakarta - Bandung toll road, Belawan - Medan - Tanjung Morawa, Jakarta - Bogor - Ciawi Highways, Semarang - Cikampek Highway, Cirebon - Brebes Highway, Surabaya - Gempol, Cirebon Highway and Semarang - Solo Highway. A significant amount of financial investment is also necessary for the maintenance of highways which is crucial for road worthiness, user satisfaction and safety [5].

Road users usually demand for a comfortable and safe riding surface. Despite the fact that aesthetics is important, it only gets the limelight when it involves pavements with heavy traffic. Ridding quality denotes the life of the pavement as perceived by the users. Road pavements which fail to deliver a comfortable and safe ridding surface will raise concerns among road users in terms of the operating cost of vehicles. Road pavement's user requirement may be quantified in terms of serviceability index. The term serviceability was initially coined at the AASHO Road Test to imply performance of pavement.

Considering the acceptable quality of the ridding quality, any early deterioration may not be spotted by road users. On the other hand, such issues must be made known to the engineers since the road performances may be enhanced by early maintenance [3]. As such, it is absolutely important to understand the flexible pavement's performance and behavior under local conditions. Careful consideration and application of the rehabilitation solutions suggested by AASHTO should be done. The suiting of the recommendations towards local conditions may need some adjustments. The engineering needs and road users must be weighed carefully to meet budget requirements, and to reap the maximum advantage via suitable maintenance processes. Historical evidence suggest that costly reconstructions may be prevented via prompt maintenance [6,7].

The distinct causes that lead to road failure have been identified via extensive investigations. Several common causes include excess loading, sub grade's consolidation, chemical degradation, bitumen's hardening, repeated axle loading, moisture and thermal alterations, densification of material, aggregate's degradation and shear in sub grade abrasion due to traffic. Swift recommendations for solutions may be helped via early detection of the aforementioned causes [4,8,9]. Accurate identification of actual modes of failure influence the accuracy and suitability of assessment processes and analysis [10,11]. Table 1 illustrates the link between modes of failure, their manifestations and mechanism.

Table-1: Relationship between failure Mode, manifestation and probable mechanism [12].

Mode	Manifestation	Common Mechanism
Fracture	Cracking	Age hardening, Excessive loading, repeated loading and moisture changes
Distortion	Permanent Deformation	Creep, Excessive loading, moisture changes, densification, consolidation
Disintegration	Stripping and Ravelling	Degradation of aggregate, lack of adhesion, chemical aggression, abrasion by traffic

Certain factors that influence pavement behavior include environmental alterations, poor drainage, axle loading and characteristics of the soil [2,13]. Environmental stresses (such as diurnal temperature) and traffic affects the strains and stresses experienced by the layers of pavement. There is also tensile strain at the upper and lower layers of the bituminous surface. Compressive stress affects the road sub grade, sub base and base [14]. Factors that influence the choice of maintenance procedure include engineering judgement, impact on gridline, road user, and feasibility of construction. The three steps include identification of problem, identification of possible alternatives and selection of preferred remedy [7].

The remedies for this issue may be hampered by insufficient or uncertain funding, challenges in plan preparation or detail design work, that can delay delivery of project [15]. Pavement condition influences the most cost-effective solution while the form of treatment involved affects the most cost-effective time to treat a pavement. Predictability of pavement deterioration over time is absolutely necessary in order to address any pavement section with certain form of rehabilitation or maintenance treatment. It is almost impossible to come up with any plan of construction of financial budget that is reflective of the pavement's needs if there is a lack of understanding on the pavement's condition at the time of construction [16]. This study's aim is to highlight the major sources of pavement distress within the district of Semarang Toll Highway, as well as to assess the effectiveness of pavement maintenance and rehabilitation in terms of cost, quality and time. The flexible pavement's performance will be assessed in this research via completed pavement maintenance and rehabilitation, in order to achieve the initial objectives.

METHODS

These procedures were used in order to meet the research objective.

Method of data collection

The most important part of this study is data collection. Used information are sub-divided into two groups: secondary and primary data.

1) Primary data refer to all real data collection from the study area, Interviews will be carry out to those are who experience and professional in road maintenance to get the relevant information to research objectives directly from the respondent and also to see expose the real condition of the road deterioration and how the maintenance is executed.
2) Secondary data can be obtained through the literature review which was done to ascertain knowledge and to gather data related to study area.

METHOD OF DATA ANALYSIS

For this study, data has been analyzed using descriptive analysis method, conducted to find whether there is any relationship of each independent variable with the dependent variables. Data analyses was conducted by using chart analysis, so the objectives were met via the selection and analysis of data from few sources and aspects.

Study area

The study area is Semarang City that is the largest city and capital of Central Java province, Indonesia. This area is up to 373.78 square kilometers, and possesses a population of approximately 6 million people. This makes it the seventh most populated city in Indonesia. Semarang City Toll Road is part of the Trans-Java toll road that links most areas of Semarang. It was constructed in year 1983 which consists of three sections A, B and C and has a direct link to Semarang–Solo Toll Road along the Tembalang Interchange and National Highway Route 1 on Kaligawe junction and Krapyak junction.

The operation and maintenance of this Toll Highway under responsibility of PT. Jasa Marga (JM), a general directorate of highways engineering. The first section was (B) constructed in year 1983 by total length 6,124 km followed by section (A) was constructed in year 1987 by total 8,300 km and section (C) was constructed by the following year 1988 by total length 10,176 km. The study's sketch map which is composed of three sections is showed in Figure 1. Merak-Brebes Timur toll road is linked to Section A. The Waru-Juanda Toll Road and Surabaya-Gempol Toll Road are also linked to Section B. There are future plans to link the Surabaya-Gresik Toll Road to section C.

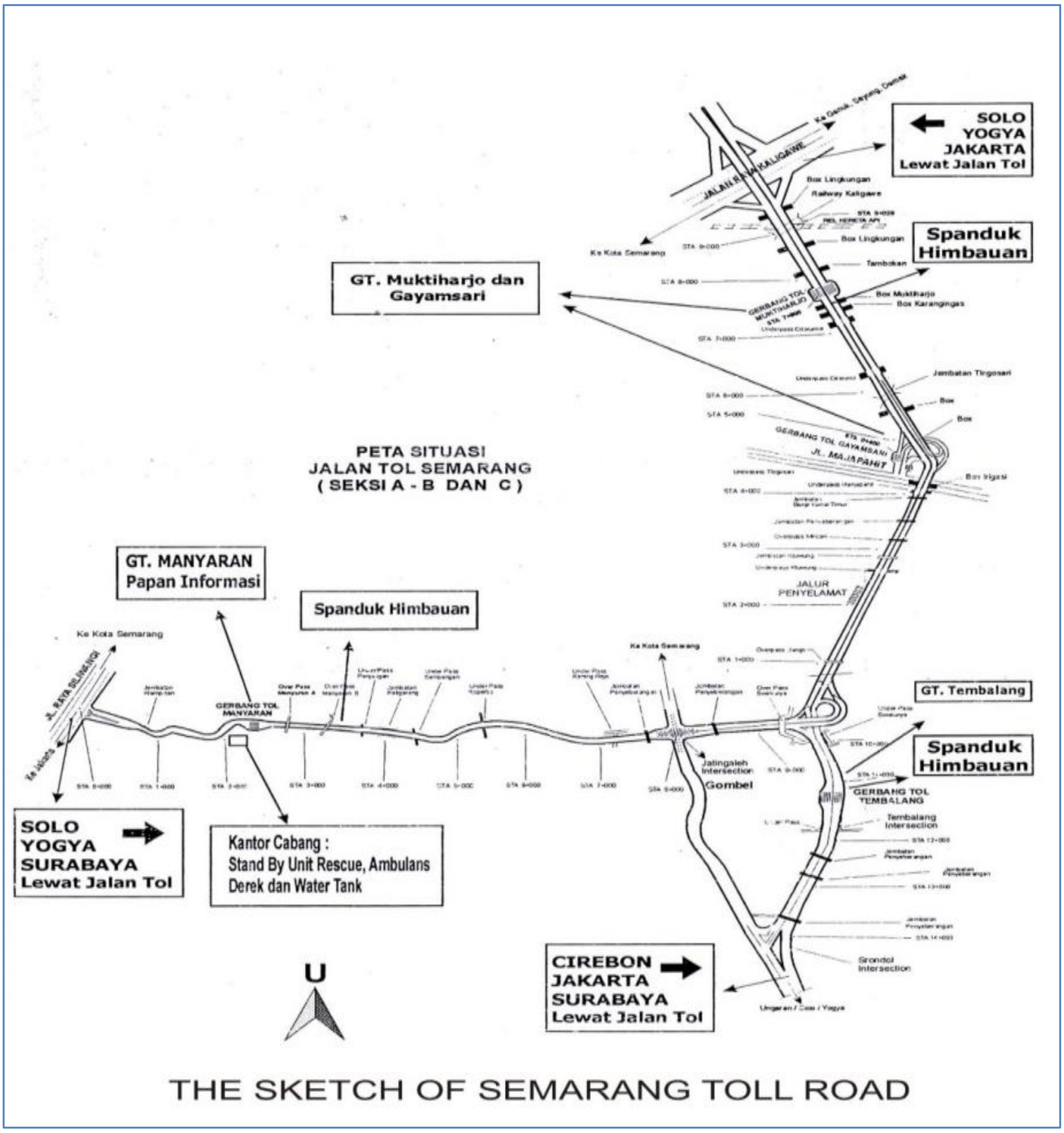


Fig-1: The sketch of study area, Semarang Toll Road (Section A, B and C)

Semarang Toll Highway started from 6,124 km and ends at 24.6 km up to 2010 with total length is 18 km. The highway concessionaire carried out their main project at the Semarang pavement maintenance and rehabilitation in September 2007. There are five major packages in five distinct executing times in the project. The project was also awarded to three major contractors with the total sum of approximately Rp 53.239.367.000. The period and cost of Maintenance and Rehabilitation efforts within the period of 2003-2010 were illustrated in Table 2.

Table-2: Cost and period of maintenance and rehabilitation activities, (PT.JASA Marga, 2010)

Section	Period of Maintenance and Rehabilitation	Contractor	Total cost (Rp)
C	2003	PT Kadi International	3.792.316.000
	2004		5.960.000.000
C	2005	PT Eka Mustika	6.446.467.000
	2006		5.026.208.000
	2007		3.332.734.000
A	2008	PT Adhi Karya (Persero) Tbk	9.329.215.000
B	2009	PT Adhi Karya (Persero) Tbk	5.767.000.000
A, B, C	2010	PT Adhi Karya (Persero) Tbk	14.167.498.000
		Total amount (Rp)	53.821.438.000

Types and Sources of Pavement Distresses

Cracks are generally fissures due to complete or partial fractures of surface of pavements. The surface cracking of road pavements may occur in various forms, such as isolated single cracks to linked patterns that extend all over the surface of pavement. The cracks' presence is linked with negative impacts such as the loss of cracked material's ability to spread, loss of pavement layer's water proofing, loss of quality of riding via impacted surfacing, loss and pumping of fines from the base course, and degraded appearance.

The loss of water proofing and ability to spready likely promote the degradation of pavement's condition. Plausible roots of crack include exceeding the surface's fatigue life, shrinkage and non-optimum construction of joints, and depression of the surface and reflection of cracks within underlying layers. The common forms of crack include crescent shaped cracks, longitudinal cracks, crocodile cracks, transverse cracks and block cracks [17,18].

Deformation of surface occurs when the surface of a road experiences alterations from its initial profile's construction. This may take place following construction as a result of environmental influence or trafficking. In certain scenarios, insufficient regulation during construction leads to deformation in a new pavement. Pavement's ridding quality may be a sign of poor structural profile. This may cause surface layers to crack [19]. Main forms of surface deformation include corrugation, shoving, rutting and depression.

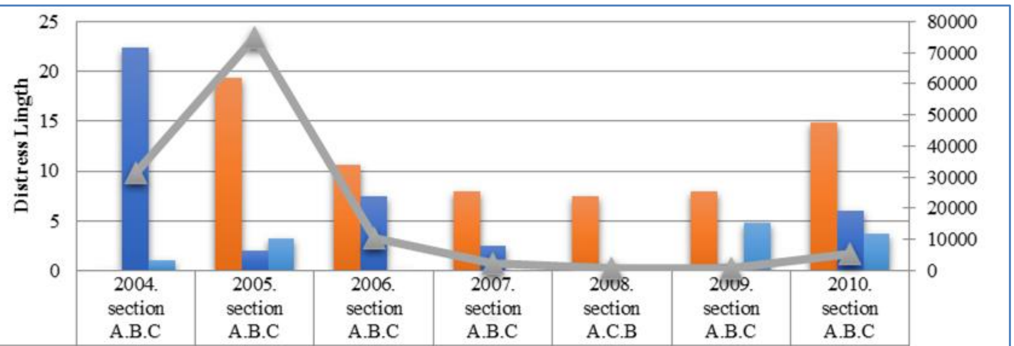
Surface defects include loss of surface macro and micro textures, as well as loss of surfacing materials. Despite the fact that they don't always reflect the inadequacy of pavement's structure, they are important in terms of pavement safety and serviceability. This is especially true in terms of quality of riding, resistance to skid and maneuverability. Certain defects eventually cause the degradation of pavement integrity. Common forms of surface defects include raveling, elimination, polishing and bleeding.

The process of choosing a pavement rehabilitation method relies on engineering judgement, feasibility of construction, costs, and impact on the road users as well as the gridline. The three steps necessary include identification of issues, identification of possible alternatives, and choosing the best solution [20]. There is a wide range of rehabilitation options of flexible pavements, and includes three major groups: Restoration, Resurfacing (structural) as well as Reconstruction [21].

RESULT AND DICUSSION

The data obtained from PT. Jasa Marga (JM), a general directorate of highway engineering showed that 24.6 km of highway drainage has been built along Toll Highway. A drainage performance test was performed by the PT. Jasa Marga (JM) to assess its functionality by using close site observation.

From Figure 2 we can see the distress length of moderate severity in year 2004 up to 22.400 km while zero high severity and 1 km low severity of drainage condition and maintenance surface area rose to 31,599.38 m². In addition, the high severity grew to 19,402 km in 2005 as compared to 2004, while zero km in 2004 and the maintenance area also increased to 75,095.72 m². and we can see a significant shift in the maintenance surface area, which drops to 10,524.69 m², then remained steady until 2009, with a maximum distress length of 8 km and a maintenance surface area of 2,481.48 m², which seems to be managed by the contractor. However, in 2010, it increased to 14.900 km of high-severity distress length, and the maintenance surface area increased to 5,559.97 m², indicating that drainage conditions and maintenance surface area would worsen in 2011.



	2004. section A.B.C	2005. section A.B.C	2006. section A.B.C	2007. section A.B.C	2008. section A.C.B	2009. section A.B.C	2010. section A.B.C
HS	0	19.402	10.55	8	7.4	7.95	14.9
MS	22.4	2	7.4	2.5	0.5	0.65	6.05
LS	1	3.2	0	0	0	4.75	3.65
Surface Area	31599.38	75095.72	10524.69	2481.48	676.15	695.37	5559.97

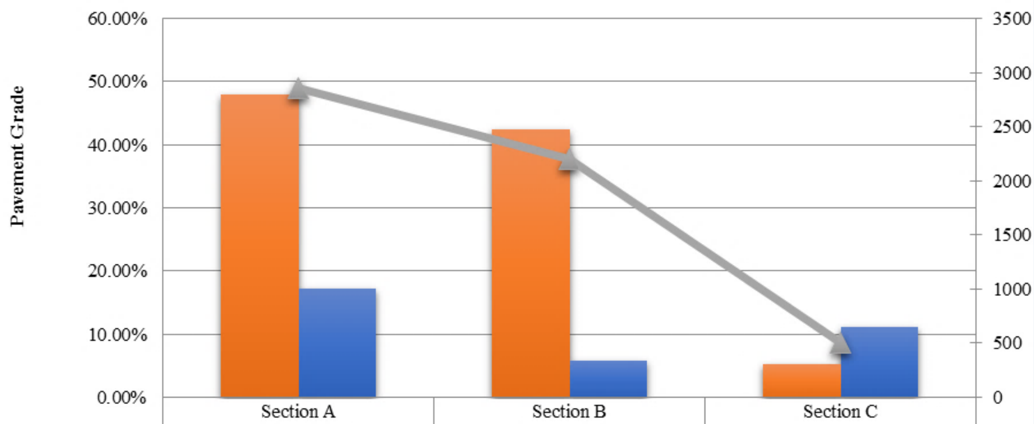
Fig-2: Graph of severity levels of drainage conditions from 2004 to 2010

The result analysis indicated that 14.9 km (60.57 %) of the drainage did not function well, while 6.05 km (24.59 %) function moderately and 3.65 km (14.84 %) functioned well, the maintenance surface area is also up to 5,559.97 m² where pavement distress has occurred.

According to the results, the highway stormwater drainage did not function well which indicates of high water seepage on the roads. From data obtained using the method of site observation, it was shown that 60.57 % of the overall drainage of the highway was often wet at a high level of severity. This condition is prone to road damage, especially on the subbase. Road failure could be influenced by a weak sub base layer. The sub base layer that is contaminated with water most typically manifests itself as cracking or deformation in a flexible pavement system.

The Toll Highway is stretched to a pavement grade of 15.7 km, which represents 64 % of the Toll Highway's overall inclination. Compared to other stations in the pavement grade stretch at Semarang Toll Highway, Figure 3 shows the amount of upwards and downwards pavement grade along Toll Highway compared to other stations in the pavement grade stretch of Semarang Toll Highway.

Figure 3 shows a summary of the upward and downward grade in all sections of the Toll Highway. The pavement grades in this figure were zoomed in for the year 2010, and sections A and B can be classified as sections with more upward than downward grades and surface area calculated by square meters to display the total maintenance surface area per section. Section A had a maintenance surface area of 2,860 m² with a high percent of upward and downward grades and fell to 2,200 m² in section B, while in section C the maintenance surface area decreased by 500.03 m² with low percent of upward and downward grades. It is very important to consider this fact because it could influence the operating cost of vehicles as well as the level of safety on these sections.



	Section A	Section B	Section C
Upward Grade	47.89%	42.46%	5.27%
Downward Grade	17.23%	5.83%	11.20%
Surface area	2860	2200.1	500.03

Fig-3: Upward and downward of pavement grade along the Toll Highway

Three forms or aspects (cost, time and quality) are taken into consideration during the evaluation of the effectiveness of methods utilized in the pavement's rehabilitation and maintenance Time.

Table 3 shows the time required to complete the maintenance and rehabilitation works. Such information was collected from contract documents.

Table-3: Time to complete pavement maintenance and rehabilitation works.

Contractor / Section	Contractor 1		Contractor 2		Contractor 3		Contractor 4		Contractor 5	
	Original duration (Weeks)	Extension of Time/weeks	Original duration (Weeks)	Extension of Time/weeks	Original duration (Weeks)	Extension of Time/weeks	Original duration (Weeks)	Extension of Time/weeks	Original duration *(Weeks)*	Extension of Time/weeks
Section C	96	12								
Section C			144	-						
Section A					48	10				
Section B							48	-		
Section A,B and C									48	4
Total weeks	108		144		58		48		52	

It was found from Table 3 that the initial pavement maintenance and rehabilitation plan for Contractor 1 was changed to 108 weeks in Section C as a result of the original contract, 96 weeks after the additional or extension time of 12 weeks from the total period of the original contract for 2003, 2004 and 2005. Although Contractor 2 was 144 weeks without extension of time in 2006 and 2007, Contractor 3 in 2008 was completed in 58 weeks with an extension of time of up to 10 weeks in 2008. Contractor 4 completed the pavement rehabilitation and maintenance works in 2009 without extending the time, and contractor 5 completed the pavement rehabilitation and maintenance works in 2010 for sections A, B, and C in 52 weeks with a four-week extension of time.

Contractors 2 and 3 both had zero extensions of time, meaning that they completed their pavement maintenance and rehabilitation work on time as stated in the contract, while the other contractors requested dissimilar extensions of time due to discrepancies in site circumstances as extra time provided leads to delay in pavement rehabilitation and maintenance. It is crucial to choose the suitable process in running pavement rehabilitation efforts. In addition to engineering judgement, other factors for instance construction feasibility, impact on gridline and other users, and costs influence the selection procedure. Due to such reasons, there are three steps that must be followed, which are identification of problem, identification of suitable alternatives and selection of preferred remedy. There should be ample focus on the issues of construction during monsoon periods.

The following are the major sources of delay:
1) Climate change effect.
2) Additional scope of work including sub-soil drain's construction.
3) Change of site conditions including sub-grade repair, that is not shown on drawings, and bill of quantity.
4) Pavement material's inadequate stock.

Quality

The information collected from the contract document highlight the ongoing damage to the pavement of the concessionaire highways which have constructed the maintenance according to the PT. Bina Marga specification used by the concessionaire Toll Highways.

The results indicated that the effect of pavement upward and downward grade pavement on corrugation is significant in both directions as corrugation occurred on upward and downward grade roads And this have showed damaged road surface recorded after the maintenance of the pavement and the rehabilitation work on the upward and downward grades. There were 4 types of pavement distress following maintenance and rehabilitation work. 11,560 km of cracks, 600 m of bleeding, 1,700 km of corrugation and 300 m of depression and cracks are the greatest distress up to 11,560 km due to excessive loading. repeated loading and moisture, changes as shown in Figure 4.

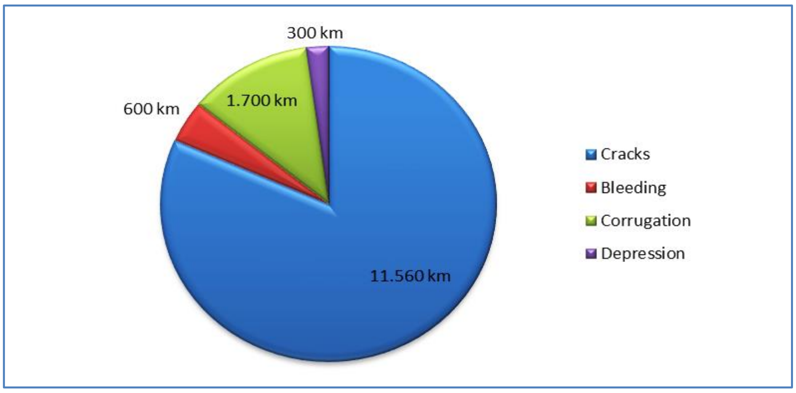


Fig-4: Total defects recorded after pavement rehabilitation

In general, a whole pavement distress is not solely caused by the quality of maintenance and rehabilitation works, but is contributed by other factors, such as drainage condition and pavement grade, as previously discussed. The pavement grade, especially upward grade, mainly contributes corrugation, while drainage condition is indirect cause of pavement cracking.

Cost

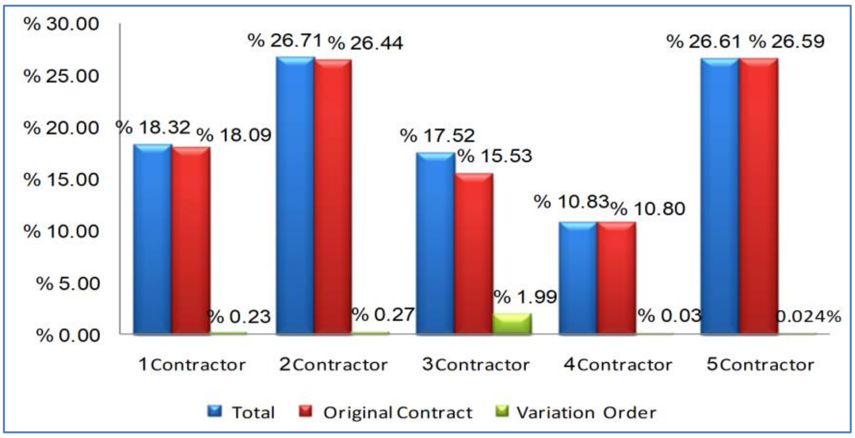


Fig-5: Cost distributions on pavement maintenance and rehabilitation of Semarang Toll Highway (Contract Amount).

Information was pooled and obtained from the site instructions, bill of quantity and certificates of claim. The recording of these information were made following financial progress up to the month of December 2010. Figure 5 shows the costs involved on the basis of the contract document. The total costs were Rp 53.239.367.000, which were divided for contractor 1 (18.32 %) in 2003 to 2005, contractor 2 (26.71 %) in 2006-2007 and contractor 3 (17.52 %) in 2008 and contractor 4 (10.83 %) in 2009 and contractor 5 (26.61 %) in 2010.

Figure 5 shows that the total cost of the original contract from 2003 to 2010 was Rp 53.239.367.000, but this amount increased by 1.62 per cent. Contractor 3 has the largest increase of 1.99% from the cumulative amount while contractor 2 has increased by 0.27% and contractor 1 has also increased by 0.23% and contractor 4 and 5 are the lowest percent by 0,03% and 0.024%, all of which vary according to time extensions. At such great amounts, the Concessionaire Company appears not to have any commitment to the maintenance and rehabilitation of pavements in order to be effective and appropriate.

CONCLUSION

This case study highlighted the two major causes of pavement distress in Semarang Expressway. The condition of the drainage and pavement grades. While collecting and obtaining data, all such causes were shown to have major impact on Semarang's pavement distress. The study showed that during the pavement maintenance and rehabilitation works, the time extension granted to the contractor was very high for all contractors as it ranged between 0.024% and 1.99%. In terms of time, the outcomes highlight the ineffective nature of pavement rehabilitation work.

Results of quality aspects show that despite the supervision and monitoring of three parties, the flexible pavement still experienced distress and damage. In echo of previous discussions, the costs of work processing in solving these issues came up to 3.63% of the original contract. Therefore, in terms of quality, this analysis showed that pavement maintenance and rehabilitation work was ineffective.

During the construction phase, there was an increase in the original cost up to 1.62%. The variance order is attributed to factors that raise this amount. The same factors could be affected by the variance in the price. Change orders have been issued with reasons to ensure that maintenance and rehabilitation work is carried out accordingly and effectively. Unfortunately, after the maintenance and rehabilitation work was done, it was found that the damage or distress had occurred and it was not under the responsibility of the contractor. The estimated cost to fix these issues is Rs 14,167,498,000 which is 3.63% of the original contract. The main factors contributing to the occurrence of these problems were the extreme severity of the drainage condition and the variation of the paving grade factors. Therefore, in terms of cost, the analysis showed that pavement maintenance and rehabilitation work were not efficient.

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REFERENCES

1. Iskandar, D., Hadiwardoyo, S. P., Sumabrata, R. J., & Fitriasari, I. N. (2018, June). Road maintenance strategy with characteristic of drainage condition based on pavement performance. In *AIP Conference Proceedings* (Vol. 1977, No. 1, p. 040010). AIP Publishing LLC.
2. Onoyan-Usina, A., Lazhi, Y. G., & Itomi-Ushi, D. P. (2013). Bad drainage and its effects on road pavement conditions in Nigeria. *Civil and Environmental Research*, *3*(10), 7-15.
3. Davies, R. M., & Sorenson, J. (2000). Pavement Preservation. *Public Roads*, *63*(4), 37-42.
4. Ragnoli, A., De Blasiis, M. R., & Di Benedetto, A. (2018). Pavement distress detection methods: A review. *Infrastructures*, *3*(4), 58.
5. Rostiyanti, S. F., & Tamin, R. Z. (2010, March). Identification of challenges in public private partnership implementation for Indonesian toll road. In *Proceedings of the First Makassar International Conference on Civil Engineering, March* (pp. 9-10).
6. Volovski, M., Murillo-Hoyos, J., Saeed, T. U., & Labi, S. (2017). Estimation of routine maintenance expenditures for highway pavement segments: accounting for heterogeneity using random-effects models. *Journal of Transportation Engineering, Part A: Systems*, *143*(5), 04017006.
7. I.L., S.., (1993). Pavement Rehabilitation Strategy Selection. American Concrete Pavement Association, Skokie, IL.
8. Al-Ghadi, M. S., Mohtar, W. H. M. W., Razali, S. F. M., & El-Shafie, A. (2020). Hydraulic Modelling Analysis for Road Stormwater Drainage Evaluation under RCPs Based Rainfall Data.
9. Ben Zair, M. M., Jakarni, F. M., Muniandy, R., & Hassim, S. (2021). A Brief Review: Application of Recycled Polyethylene Terephthalate in Asphalt Pavement Reinforcement. *Sustainability*, *13*(3), 1303.
10. Mladenovic, G., Cirilovic, J., & Queiroz, C. (2011). Optimization of Road Maintenance and Rehabilitation on Serbian Toll Roads. In *Eighth International Conference on Managing Pavement Assets* (pp. 1-9).
11. Specifications, T., Airport, D.I. (2020). Issued For Bid TC-1 March 2020.
12. Huang, Y.H. (2004). Pavement analysis and design. Inc., New Jersey Highway Re: p. 805, Doi: https://trid.trb.org/view/374362.
13. Al-Ghadi, M. S., Mohtar, W. H. M. W., Razali, S. F. M., & El-Shafie, A. (2020). The Practical Influence of Climate Change on the Performance of Road Stormwater Drainage Infrastructure. *Journal of Engineering*, *2020*.
14. Fu, Q., Chen, X., Cai, D., & Lou, L. (2020). Mechanical characteristics and failure mode of Asphalt concrete for Ballastless track substructure based on in situ tests. *Applied Sciences*, *10*(10), 3547.
15. Alfakhri, A. Y., Ismail, A., Khoiry, M. A., Albrka, S. I., Alshetwi, A. B., & Alghadi, M. S. (2018). A Study of Identifying Significant Variables of Delays in Road Construction Via Structural Equation Modelling (SEM). *International Journal of Engineering & Technology*, *7*(2.29), 893-898.
16. Camahan, J. V., Davis, W. J., Shahin, M. Y., Keane, P. L., & Wu, M. I. (1987). Optimal maintenance decisions for pavement management. *Journal of Transportation Engineering*, *113*(5), 554-572.
17. Lavin, P. (2003). *Asphalt pavements: a practical guide to design, production and maintenance for engineers and architects*. CRC Press.
18. Huang, Y., Bird, R., & Heidrich, O. (2009). Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. *Journal of Cleaner Production*, *17*(2), 283-296.
19. Mirzahosseini, M. R., Aghaeifar, A., Alavi, A. H., Gandomi, A. H., & Seyednour, R. (2011). Permanent deformation analysis of asphalt mixtures using soft computing techniques. *Expert Systems with Applications*, *38*(5), 6081-6100.
20. Rani, O.A. (2007). The Effectiveness of Pavement Rehabilitation at Kuala Lumpur Karak Highway. Master thesis, Universiti Teknologi Malaysia. Universiti Teknologi Malaysia.
21. Preservation, C.D. of T.O. of P. (2003). Maintenance technical advisory guide (TAG). California Department of Transportation.