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Risk-based Maintenance Model for Road Network

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Abstract **-** Road is an asset for a country to develop. To be able to serve until its planned service period road needs maintenance. On the other hand maintenance does needs budget to deal with. As budget for maintenance is limited, cost optimization becomes very important.
This research used risk-based maintenance model and multi-criteria decision making and weight method for a road network. For this study we chose a road network comprised of seven roads. The road network comprised of jl. Sirodjuddin, jl. Prof. Sudharto, jl. Setiabudi, jl. Gombel Lama, jl. Gombel, jl. Teuku Umar and jl. Dr. Wahidin. The data we needed came from assessing each road's surface condition and questionnaire where some professionals in civil engineering actively involved.
From the data we gained and analysed, we found a risk category for each road. From the risk category we would be able to develop maintenance action plan for each road. Based on the maintenance action plan, cost optimisation will be achieved.

Keywords : road maintenance, risk-based maintenance model, road network, analytical hierarchy process

1. Introduction

There are a lot of factors affecting traffic smoothness such as traffic volume, road condition, the current situation and environment. Those factors support traffic condition collectively. But a good road condition will be useless if the traffic volume on a road is overloaded. On the other hand a good road condition will be also useless when the environment around the road does not support the traffic, e.g. there is a construction work causing traffic jam, or as usual we say a bottle-neck situation. Such obstacles we find on the road will impede our travel and decrease our productivity, therefore maintenance or at least inspection should be done regurlarly.

This research is on the planning stage of maintenance management. The aim of this research was to propose a road maintenance planning based on risk analysis. The research object was a road network in Semarang. The network consisted of seven roads, they were jl. Sirodjuddin, jl. Prof. Sudharto, Jl. Setyabudi, jl. Gombel Lama, jl. Gombel (with the Panorama Restaurant on it), jl. Teuku Umar (Jatingaleh) and jl. Dr. Wahidin. The reason we chose this network was because the network connects important destinations in the city, such as Sint Louis High School, Karangpanas Church, Jatingaleh traditional market and Diponegoro University. Aside of the busy traffic on these road, the landscape of each road was also took into our consideration. Jl. Gombel (jl. Gombel Lama and jl. Gombel) and jl. Dr. Wahidin lie on steep slopes, while jl. Prof. Sudharto and jl. Setiabudi are on the flat landscapes, it makes them have different kind of potential risks . The environment around every road is also different from one to another, e.g. jl. Dr. Wahidin is 10 metre wide and surrounded by houses, so there is not very often traffic

jam happened on this road, while jl. Prof. Sudharto is only 6 metres wide, full of student appartments and restaurants, and as a result sometimes there were traffic jams on this road in certain hours.

Every road within the network was analysed based on the potential risk that commonly happened to the traveller. A potential risk means a situation that causes someone to experience loss or in danger (Phil Hughes et al. 2005). This research bore a rank for every road based on the level of risk. The riskiest road would be on the top rank, on the contrary the least riskiest road would be on the last rank.

2. Methodology

The methodology of the research were :

1. Building the list of potential risks that might be happened on a road (the likelihood of road deterioration causing factors).
2. Building the list of the consequences of the potential risks.
3. Finding the total relative importance score for each potential risk and the consequences over the other risks and the consequences respectively.
4. Doing risk analysis and made a rank of roads based on the risk category.

We applied Analytical Hierarchy Process method to get the relative score for each potential risk and the consequences. The AHP analysis was started by building questionnaires about the preference data of road risks and the consequences. The questionnaire tried to find out the most dominant risks on the road network and the consequences.

The Analytical Hierarchy Process is a multi criteria decision making introduced by Saaty (1970). The AHP technique was adopted because it accomodated all the criteria we considered and enabled practitioners to give their judgement.

3. Risk Identification

3.1. The Road Deterioration Causing Factors

By doing interviews and literature study the writers found that factors causing road deterioration were road damages, initial design error and the environment. The damages was then subdivided into surface roughness, potholes, patches, cracks, rutting and depression. The initial design error was subdevided into error in road geometry planning and mistake on pavement type design. The Environment was subdevided into the environment caused by nature and human.

3.2. The Consequences of Road Deterioration

The consequences of road deterioration were built from the interview with many colleagues, the news from the newspapers and the writers' experience when travelling on the road network those days and still now. The consequences that emerged from a road deterioration were devided into two categories, economics and social and environment. The economics category was subdevided into productivity, broken vehicle and fuel wastes, economic stagnation and a more expensive road repair in the future. The environment and social category was subdevided into causing accident, air pollution and voice pollution.

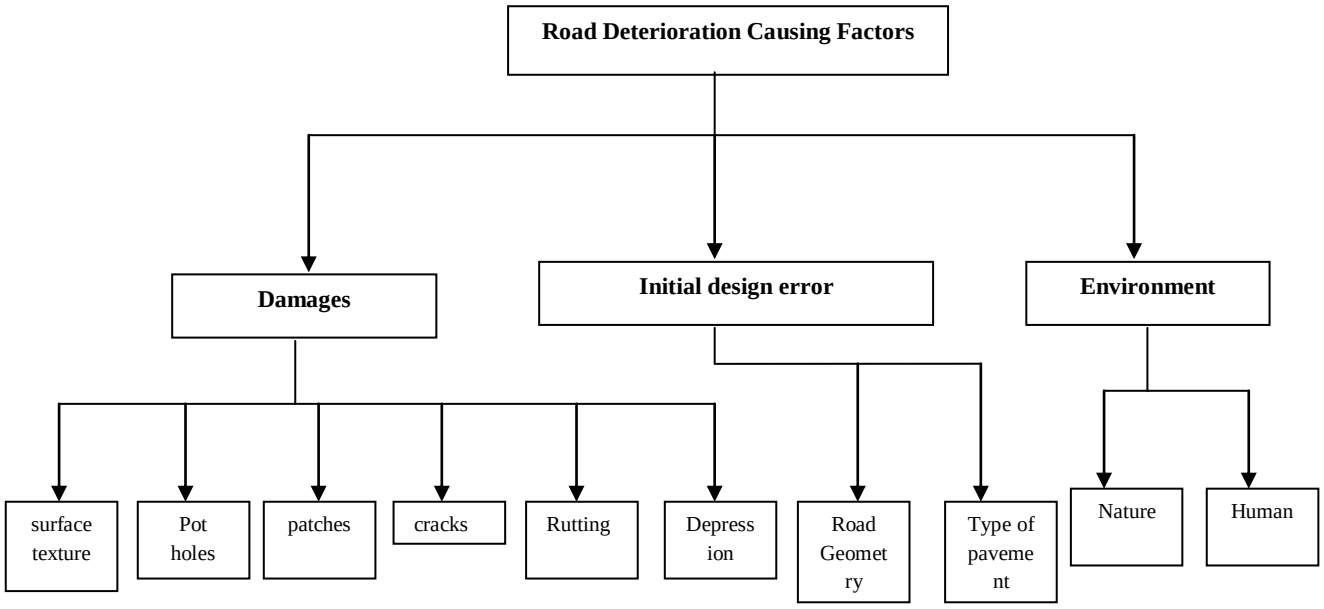

Fig. 1. Road Deterioration Factors Diagram

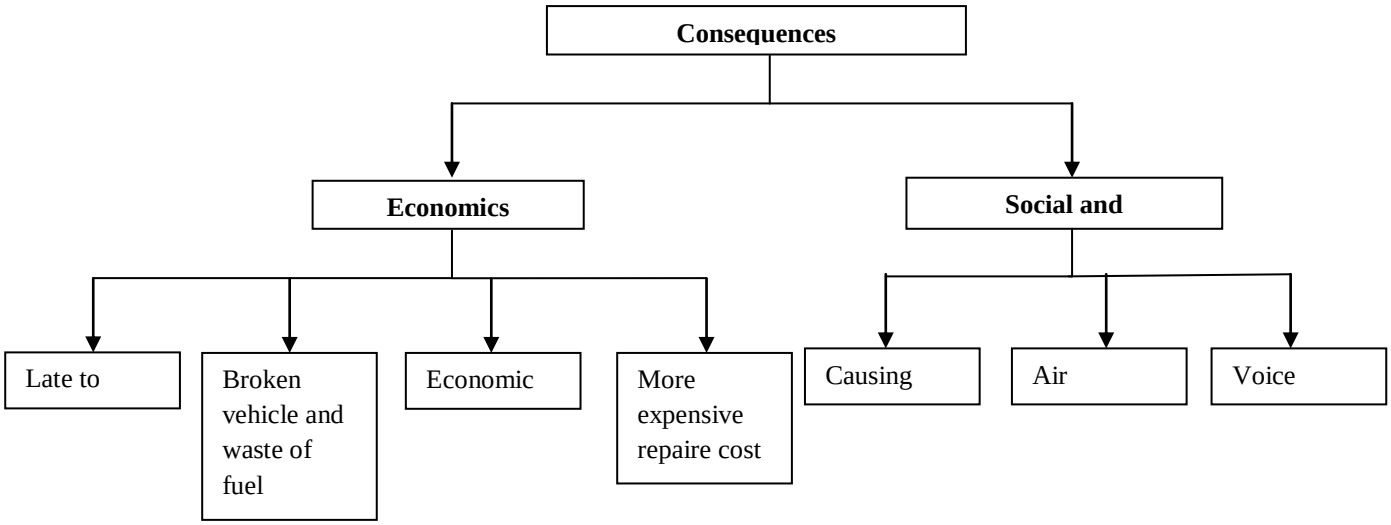

Fig. 2. Consequences Diagram

4. Risk Analysis

Risk analysis consisted of two steps, finding the total importance score of each factor and sub factor and analysing road condition to find each road risk category.

4.1. Finding the Total Relative Importance Score.

Questionnaires were built based on the road deterioration factors and sub factors and the consequences. The road deterioration factors and sub factors questionnaire tried

to find out what is the road deterioration factors and subfactors that the most influence the road deterioration. While the consequences questionnaire tried to find what is the most likely unpleasant incident to occur. Seven practitioners of a consultant and a contractor firms were asked to give the pairwise comparison. The questionnaires were then analysed using the Analitycal Hierarchy Process technique. The results are on the Table 1 and Table 2.

The analysis revealed that error in geometry planning was the most influencing factor in road deterioration. The second rank in road deterioration causing factor was natural factor and then potholes.

On the consequences, causing accident was on the first rank for road deterioration incident. The second rank was economic stagnation and the third rank was a more expensive road repair in the future.

The total relative importance score was used as a weighted factor to find road rank under the likelihood of road deterioration factors and the consequences categories. The results is on the Table 3.

4.2. Analysing road condition.

The condition of the road was analysed by subjective and objective judgement. In the likelihood category, the objective judgement were applied to : surface roughness, holes, patches, cracks, rutting, and depression. The objective judgement was done by onsite survey on each road within the network. While the other factors such as error in geometric planning, mistake in pavement type design, natural factors and human factors were analysed by subjective judgement, as it was difficult to measure the likelihood of those factors to occur quantitatively. In the consequences, all of the risk were analyzed using subjective judgement. The subjective judgement was used to analyzed the consequences because the severity of the risk might different from one person to another.

The objective judgement analysis found that jl. Gombel Lama and jl. Prof. Sudharto had the same degree of damage. The damage both on jl. Gombel Lama and jl. Prof. Sudharto were mostly about surface roughness, patches and cracking, only the intensity of each damage category was different. On jl. Gombel Lama had slightly more patches than on jl. Prof. Sudharto, while on jl. Prof. Sudharto had slightly more cracks than on jl. Gombel Lama. We used the standard from Bina Marga to do the assessment of the physical condition of the roads.

The subjective judgement analysis for the road deterioration factors and the sub factors likelihood bore scores for each road under certain factors and the sub factors categories,e.g. likelihood score for human factors on jl. Prof. Sudharto. This score illustrated the likelihood of the human factors in influencing jl. Prof. Sudharto deterioration. The subjective judgement for the consequences bore scores for each road for the consequence likelihood that might occur to the road, e.g. the likelihood score for economic stagnation on jl. Sirojudin illustrated the likelihood of economic stagnation to be occured should jl. Sirojudin deteriorated.

An analysis was then done to find each road rank within the likelihood and the consequences categories. Table IV and Table V show the result. The analysis tried to find the weight of each road within the network under the likelihood and the consequences categories. The weight of each road can be determined using the Eq. (1) :

$$W_{CA(jl.Sirojudin)} = \left[\frac{S_{CA(jl.Sirojudin)}}{S_{CA(Total)}}\right] x\, TRS_{CA} \quad (1)$$

Where for example, CA stands for 'Causing Accicent', $W_{CA(jl.Sirojudin)}$ was the weight of jl. Sirojudin for 'Causing Accident' category, $S_{CA(Jl.Sirojudin)}$ was the 'Causing Accident' score of jl. Sirojudin, $S_{CA(Total)}$ was the total score of all the road within the network for 'Causing Accident', and TRS_{CA} was the total relative importance score for ' Causing Accident'.

From the likelihood category, it was found that jl. Gombel Lama was the most vulnerable road for the likelihood of road deterioration factors and the sub factors to occur. The second rank was jl. Prof. Sudharto and the third rank was jl. Gombel. In the consequences, jl. Gombel Lama was also the on the first rank on the vulnerability of the consequences to occur. The second rank was jl. Gombel and the third rank was jl. Teuku Umar.

Here we can see that the road with the high score for the likelihoodof factors and the sub factors might not have the high score for the vulnerability of the consequences. Since both effected each other (i.e. the consequences would occur should the factors of road deterioration occured), to find the risk category of each road was then by multiplying the likelihood and the consequences score. The scores depend on the rank of the road (Table VII). The multiplication of the scores result was the risk score of each road and then converted into risk category (Table VI). The risk analysis found that the riskiest road was jl. Gombel Lama, followed by jl. Gombel and then jl. Teuku Umar. The result is on the Table VIII.

Table 1. Likelihood of the Risk Factors

The Likelihood of Factors Causing Road Deterioration	Experts							Average	SD
	1	2	3	4	5	6	7		
Damages	0,41259895	0,732431	0,6586442	0,1958004	0,6586442	0,626696	0,412599	0,52820196	0,192639
Surface Roughness	0,12355758	0,124214	0,118698	0,1178169	0,1238947	0,116151	0,125501	0,12140483	0,003726
Potholes	0,23056659	0,216269	0,2333967	0,2384257	0,2246394	0,232302	0,234194	0,22997052	0,007337
Patches	0,14193038	0,137015	0,1461344	0,1314982	0,1327871	0,133422	0,134509	0,13675665	0,005391
Cracks	0,18727827	0,182934	0,1820441	0,1618933	0,1752136	0,176052	0,203878	0,1813276	0,012845
Rutting	0,14193038	0,163902	0,1631039	0,1510518	0,1752136	0,139843	0,1656	0,15723492	0,01321
Depression	0,1747368	0,175665	0,1566229	0,199314	0,1682514	0,20223	0,136317	0,17330547	0,023068
Initial Design Error	0,25992105	0,137849	0,185174	0,493386	0,185174	0,279688	0,259921	0,25730176	0,116135
Error in Road Geometry Planning	0,25	0,875	0,8333333	0,5	0,9	0,5	0,75	0,65833333	0,245374
Mistake on Pavement Type Design	0,75	0,125	0,1666667	0,5	0,1	0,5	0,25	0,34166667	0,245374
Environment	0,32748	0,129721	0,1561818	0,3108137	0,1561818	0,093616	0,32748	0,21449628	0,102801
Natural Factor	0,5	0,5	0,5	0,5	0,5	0,666667	0,833333	0,57142857	0,131133
Human Factor	0,5	0,5	0,5	0,5	0,5	0,333333	0,166667	0,42857143	0,131133

Table 2. Consequences of the Risk Factors

The Consequences of Road Deterioration	Experts							Average	SD
	1	2	3	4	5	6	7		
Economics	0,5	0,5	0,5	0,125	0,75	0,75	0,5	0,51785714	0,20952
Productivity (e.g. late to work)	0,06558259	0,099105	0,0804064	0,0484257	0,0781077	0,093046	0,03457	0,07132045	0,023382
Broken Vehicle and Waste of Fuel	0,20739035	0,250011	0,2366225	0,2962154	0,5035932	0,161161	0,120371	0,25362354	0,124528
Economic Stagnation	0,51626341	0,297315	0,4747169	0,3222105	0,1275494	0,308918	0,58738	0,37633615	0,157804
A More Expensive Road Repair in the Future	0,21076365	0,353569	0,2082542	0,3331484	0,2907497	0,436875	0,257679	0,29871987	0,082613
Social and Environment	0,5	0,5	0,5	0,875	0,25	0,25	0,5	0,48214286	0,20952
Causing Accident	0,81818182	0,818182	0,6838819	0,7777778	0,7777778	0,593634	0,777778	0,74960179	0,082091
Air Pollution	0,09090909	0,090909	0,1580591	0,1111111	0,1111111	0,249311	0,111111	0,13178873	0,05646
Voice Pollution	0,09090909	0,090909	0,1580591	0,1111111	0,1111111	0,157056	0,111111	0,11860948	0,0281

Table 3. Total Relative Importance Score

Total Relative Importance Score			
	RS	TRS	Rank
Factors Causing Road Deterioration			
Damages	0,528202		
Surface Roughness	0,121405	0,0641263	10
Potholes	0,229971	0,1214709	3
Patches	0,136757	0,0722351	9
Cracks	0,181328	0,0957776	4
Rutting	0,157235	0,0830518	8
Depression	0,173305	0,0915403	6
		0,528202	
Initial Design Error	0,257302		
Error in Road Geometry Planning	0,658333	0,1693903	1
Mistake on Pavement Type Design	0,341667	0,0879114	7
		0,2573018	
Environment	0,214496		
Natural Factor	0,571429	0,1225693	2
Human Factor	0,428571	0,091927	5
		0,2144963	
The Consequences of Road Deterioration			
Economics	0,517857		
Productivity (e.g. late to work)	0,07132	0,0369338	7
Broken Vehicle and Waste of Fuel	0,253624	0,1313408	4
Economic Stagnation	0,376336	0,1948884	2
A More Expensive Road Repair in the Future	0,29872	0,1546942	3
		0,5178571	
Social and Environment	0,482143		
Causing Accident	0,749602	0,3614151	1
Air Pollution	0,131789	0,063541	5
Voice Pollution	0,118609	0,0571867	6
		0,4821429	

5. Maintenance Plan

The maintenance plan depended on the risk analysis result. The riskiest road is the road with the highest score in the multiplication of the likelihood and the consequences score. The riskiest road means that this is the road that should be prioritized among other roads within the network in planning the network's maintenance. With the prioritazion, resource allocation can be made based on the risk of each road.

In this case, according to the risk analysis result, the riskiest risk was jl. Gombel Lama, the second riskiest was jl. Gombel and then jl. Teuku Umar. A maintenance plan of this road network should prioritize the allocation of resource to jl. Gombel Lama and the other roads will follow based on their risk category.

Risk analysis also revealed the possibility of a deterioration factors and the sub factors to occur for each road, this was done by finding the total relative importance relative score, for example, from the Table 3, jl. Prof. Sudharto had the cracking score of 0,028733, which is higher than jl. Setiabudi which had the cracking score of 0,003193, it means jl. Prof. Sudharto was more vulnerable of the occurence of cracking than jl.Setiabudi. The travelller's road risk might reduced should the maintenance action plan giving more attention to prevent cracks on jl. Prof. Sudharto. This findings was true as jl. Prof. Sudharto is one of the main access to Diponegoro University, where the traffic was always crowded, the populaiton is also growing as there are a lot of student apartments around the road, while jl. Setiabudi was not as crowded as jl. Prof. Sudharto, moreover it has higher road class.

Table 4. Total Relative Importance Score of Likelihood

The Likelihood of Road Deterioration Causing

Street Name	Surface Roughness	Potholes	Patches	Cracks	Rutting	Depression	Error in Road Geometry Planning	Mistake on Pavement Type Design	Natural Factor	Human Factor	Total Score	Rank	Risk Score 1
jl. Sirojudin	0,01068771	0	0	0,003193	0	0	0,019148472	0,014160231	0,018328	0,015008	0,080526	6	1
jl. Prof. Sudharto	0,02137542	0	0,01805878	0,028733	0	0	0,011783675	0,010620173	0,01031	0,016259	0,11714	2	5
jl. Setiabudi	0	0	0	0,003193	0	0	0,011783675	0,011210183	0,01031	0,013132	0,049628	7	1
jl. Gombel Lama	0,02137542	0	0,03611756	0,025541	0	0	0,047134699	0,01652027	0,030929	0,010631	0,188248	1	6
jl. Gombel	0	0	0	0,003193	0	0	0,041242862	0,013570221	0,027492	0,00938	0,094878	3	4
jl. Teuku Umar	0	0	0,01805878	0,028733	0	0	0,016202553	0,005310087	0,012601	0,013132	0,094038	4	3
jl. Dr, Wahidin	0,01068771	0	0	0,003193	0	0	0,02209439	0,01652027	0,012601	0,014383	0,079479	5	2

Table 5. Total Relative Importance Score of Consequences

The Consequences of Road Deterioration .

Street Name	Productivity (e.g. late to work)	Broken Vehicle and Waste of Fuel	Economic Stagnation	A More Expensive Road Repair in the Future	Causing Accident	Air Pollution	Voice Pollution	Total Score	Rank	Risk Score 2
jl. Sirodjuddin	0,004355401	0,014365396	0,023386604	0,017275496	0,034681252	0,007159549	0,006906608	0,10813	7	1
jl. Prof. Sudharto	0,004529617	0,016417595	0,02494571	0,023557495	0,040157239	0,00760702	0,007182872	0,124398	6	1
jl. Setiabudi	0,005923346	0,018469794	0,029623031	0,023557495	0,049283884	0,009396908	0,008011665	0,144266	5	2
jl. Gombel Lama	0,933606923	0,021548093	0,029623031	0,023557495	0,060235858	0,010291851	0,009116723	1,08798	1	6
jl. Gombel	0,005574914	0,021548093	0,029623031	0,023557495	0,062061187	0,009844379	0,008840458	0,16105	2	5
jl. Teuku Umar	0,005400698	0,019495894	0,029623031	0,021201745	0,058410529	0,010291851	0,008840458	0,153264	3	4
jl. Dr, Wahidin	0,005400698	0,019495894	0,028063924	0,021986995	0,0565852	0,008949436	0,00828793	0,14877	4	3

Table 6. Risk Matrix

Category of Risk	Range of Risk Value
Critical	31-36
High Risk	25-30
Medium to High Risk	19-24
Medium Risk	13-18
Low to Medium Risk	7-12
Low Risk	1-6

Table 7. Risk Score Matrix

Rank	Risk Score
1	6
2	5
3	4
4	3
5	2
6-7	1

Table. 8 Summary of Risk Category

Street Name	Likelihood Score	Consequences Score	Risk Score	Risk Category
jl. Sirodjuddin	1	1	1	Low Risk
jl. Prof. Sudharto	5	1	5	Low Risk
jl. Setiabudi	1	2	2	Low Risk
jl. Gombel Lama	6	6	36	Critical
jl. Gombel	4	5	20	Medium to High Risk
jl. Teuku Umar	3	4	12	Low to Medium
jl. Dr, Wahidin	2	3	6	Low Risk

6. Conclusion

This paper was trying to develop risk-based maintenance model for road network. The risk analysis was a combination between the likelihood and the consequences score. The likelihood score was the score of the road that is the most vulnerable of the road deterioration factors. The consequences score was the road score of the vulnerability of the consequences to occur should the factors of deterioration occures.

The analysis found that jl. Gombel Lama is the riskiest road within the network, with this finding a maintenance plan action should give more attention to this road than any other roads within the network. In case there is a limitation in resources, resource allocation should be prioritized to the most riskiest road, which in turn lead to resource optimization.

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