Financial economic cost on gravel road maintenance: study using HDM-4

F Suwarto ¹ and S Fauziyah ¹

¹Diponegoro University, Semarang, Indonesia

Abstract. This study demonstrates the economic benefit analysis from two alternative project on gravel road surface using HDM-4 to access the most appropriate project and maintenance standard both in term of pavement remaining life and also road user cost (RUC). The two alternative projects will be treated with different work standards. First Alternative namely “Without Project” will only be maintain the existing project with grading every six months, spot re-graveling to replace 30% of material lost each year, and gravel resurfacing. Second Alternative namely “With Project” will be maintaining and upgrading the existing road pavement to bituminous pavement in year 2019 for section A001-01 and for section A001-02 in year 2020, by doing grading every six months and spot re-graveling to replace 30% of material lost each year. In conclusion, from two proposed alternatives, although it requires more funds at earlier stages ‘with project’ alternative is the most appropriate project considering the number of maintenance followed, overall road performance, RUC, and the values of NVP and IRR.

1. Introduction

More than 57% of rural road in Indonesian districts is in non-stable condition. Currently, unsealed roads are still common in some areas in Indonesia. Based on road condition data from the ministry of public works, total unsealed road pavement in Indonesia in the end of year 2016 is 218.260 km [1]. Whereas rural road is very important, as the development of rural roads brings multiple socio-economic benefits to the rural areas that form a strong base of the National economy so that the existence of gravel road needs particular attention and preservation to be able to comprise with the traffic. Road networks are always significant for national productivity, local economic growth and individual social wellbeing [2].

The perseverance of the roadway is to carry on the road traffic safely and comfortably within the economic benefit capacity in term of both road user cost and road user agency, therefore several aspects have to be taken into consideration when designing and planning maintenance of a roadway. The examination can be analysed and assessed based on the feature of road geometric, pavement condition and traffic volume with different treatment of project and maintenance. The purpose of road maintenance itself is to reduce the degree of road deterioration on a continuous basis. Different treatment that carried out will have different maintenance effect, therefore it will lead to different performance as over period of time.

The difficulty of these interactions and certain numbers of data means that a computer modelling is necessary. The best-known example of a road investment model is the Highway development and management tool (HDM-4) [3]. The main area of analysis that can be undertaken using HDM-4 are Project analysis, Programme analysis and Strategy analysis [4]. For the strategic analysis purpose, the
HDM-4 will propose the appropriate maintenance approaches and develop the economic analysis of the project by derive optimal capital and recurrent maintenance and hence preserve the road network in a good condition on a sustainable basis [5]. The prioritization for pavement maintenance is done on the basis of Net Present Value by Agency Capital Cost (NPV/CAP) value [6]. HDM-4 is a comprehensive model for prioritizing pavement rehabilitation and maintenance, this model generates the total life cycle condition and costs, and provide economic decision for multiple alternative maintenance [7]. The application of HDM-4 has been extensively used for the management of road networks in many countries. [8] performed the HDM-4 to define road works program and investment priorities of 13 roads Bosnia and Herzegovina local road. The application also used in Mumbai India as a tool to plan pavement maintenance strategies on 60 km road length of urban roads to maximize the value of NPV and the desirable IRI [9]. The utilization of the model to generate fuel consumption also has been reported by [10] and [11] In this research HDM-4 will propose the appropriate maintenance approaches and develop the economic analysis of the project.

Hence the aim of this report is to analyse and estimate the economic benefits from gravel road segment by conducting two different strategic planning. The project analysis will consider the economic feasibility of two projects alternative. The objectives of this report are:

- Analyse the prediction of road deterioration with road roughness as the reference
- Analyse the road user cost (RUC) of two project alternatives
- Analyse economic comparison of two the project alternatives

2. Methodology
This report demonstrates the economic benefit analysis from two alternative project on gravel road surface using HDM-4 to access the most appropriate project and maintenance standard both in term of pavement remaining life and also road user cost (RUC). The operation of the program is defined on the three stages, the first stages is define road data requirement including road network and vehicle fleet, the second stage is define the maintenance and road improvement work in the Work Standard sector, then the last stages in the Project Analysis section is to define the candidate project and the treatment required in each project.

2.1. Case Study Data
The Case study data has been given to be analysed by HDM-4, both alternative project classified as a secondary road and located in sub-tropical/humid climate. The road network is divided into section 1 and section 2 with different characteristic in terms of road geometric and pavement structure as given in appendix 1. The road length is assumed as 20 km length for section one and 30 km length for section two and both section have 7m carriage width with no shoulder width. For the structure, both sections are assumed almost identically with the thickness of gravel 145mm for section one and 140 for section two then the road roughness is given as high as 8.5 IRI for section one and 9 IRI for section two.

Road traffic composition is assumed as low traffic class and the heaviest vehicle type will be 4+ axle artice with the traffic growth maximum 4% per year as seen in table 1. In addition, the road sections is defined as State Road and vehicle fleet are within National Fleet.

| Vehicle Name       | Annual Growth | Traffic Composition |
|--------------------|---------------|---------------------|
|                    |               | Section One | Section Two |
| 2-axle Truck       | 4%            | 32          | 27          |
| 3-axle Heavy Truck | 4%            | 15          | 25          |
| 4+axle Artic       | 4%            | 15          | 15          |
| Bus                | 4%            | 60          | 45          |
2.2. Road Work Standard

The two alternative projects will be treated with different work standards. First Alternative namely “Without Project” will only maintain the existing project with grading every six months, spot re-gravelling to replace 30% of material lost each year, and gravel resurfacing. Second Alternative namely “With Project” will be maintaining and upgrading the existing road pavement to bituminous pavement in year 2019 for section A001-01 and for section A001-02 in year 2020, by doing grading every six months and spot re-gravelling to replace 30% of material lost each year.

For the purpose to carry out the project, upgrading and road maintenance standard have to be defined in the HDM-4 software under Work Standard sector, the associated works are given in table 2 as follow. For ‘Without Project’ alternative, the work assigned is Gravel Road Maintenance. Whereas for ‘With Project’, the road network was given three main works which are maintenance standard for gravel road prior to upgrading, improvement standard representing the upgrading works, and maintenance standard for paved road after upgrading.

Table 1. Traffic data (cont.)

| Vehicle Name | Annual Growth | Traffic Composition |
|--------------|---------------|---------------------|
|              |               | Section One | Section Two |
| Motor Car    | 4%            | 115         | 95         |
| Motorcycles  | 4%            | 35          | 35         |
| Utilities van| 4%            | 48          | 40         |
| TOTAL        |               | 320         | 272        |

Table 2. Road works standard for each project alternative

| Project alternative | Section ID | Road Works Standards | Effective from year | Maintenance works/ Improvement type |
|---------------------|------------|----------------------|---------------------|-------------------------------------|
| Without Project     | A001-01   | Gravel Road Maintenance (GRAVEL) | 2019               | Upgrading (GRADE6)                   |
| Maintain Gravel Road| A001-02   | Gravel Road Maintenance (GRAVEL) | 2019               | Spot re-gravelling (SPG100)          |
|                     | A001-01   | Maintenance before upgrading (BEFORE) | 2019             | Gravel resurfacing (RESURF)          |
|                     | A001-01   | Pave Section A001-01 in 2019 (PAVE01) | 2019             | Grading (GRADE6)                     |
| With Project Upgrade| A001-02   | Crack sealing, patching and resealing paved road (SEAPAT) | 2020             | Crack sealing (SEAL)                 |
| Gravel Road        | A001-02   | Maintenance before upgrading (BEFORE) | 2019             | Upgrading                            |
|                     | A001-02   | Pave Section A001-02 in 2020 (PAVE02) | 2020             | Cracking (SEAL)                      |
|                     | A001-02   | Crack sealing, patching and rescaling paved road (SEAPAT) | 2021             | Patching (PATCH)                    |
The breakdown of road standard for maintenance works including the intervention level and costs are given in table 3. Intervention level is the limit point of the defect level where if the limit is exceeded then certain maintenance must be conducted. As seen from the table that the trigger of intervention level for maintenance before and after road upgrading is different. For the maintenance before road upgrading the trigger is the maximum year and the gravel thickness, while for the maintenance after road upgrading the trigger is the number of cracking and potholes.

Table 3. Intervention limit and maintenance cost

| Road works standard | Effective from year | Maintenance works | Code       | Intervention    | Max IRI | Costs       |            |            |
|---------------------|---------------------|-------------------|------------|-----------------|---------|-------------|------------|------------|
|                      |                     |                   |            | Grade           | 2 times per year | -         | 720 per km  | 900 per km |
| Gravel Road         | 2019                | Spot re-gravelling | SPG100     | GT < 100mm      | -       | 12 per m3   | 12 per m3  |
| Maintenance         |                     | Gravel            | RESURF     | GT < 50mm       | -       | 12 per m3   | 14.4 per m3|
|                     |                     |                   | Grade      | 2 times per year | -       | 720 per km  | 900 per km |
| Maintenance before upgrading | 2019 | Spot re-gravelling | SPG100 | GT < 100mm      | -       | 12 per m3   | 12 per m3  |
| Crack sealing and patching paved road | 2020 | Crack sealing | CRSEAL     | 5% Cracking     | 9       | 5 per m2    | 6 per m2   |
|                     | (section 1)         | Patching          | PATCH      | 10 ≥ Potholes   | 9       | 12 per m2   | 14.4 per m2|
|                     | (section 2)         | Re-sealing        | RSL7       | Interval of 7 years | 12      | 4 per m2    | 5 per m2   |

The breakdown of road improvement is given in table 4. where B is before upgrading and A is after upgrading.

Table 4. Upgrading works detail

| Section ID | A001-01 | A001-02 |
|------------|---------|---------|
| Section Name | Section One | Section Two |
| Speed flow type and Accident class | Two lane road | Two lane road |
| Traffic flow pattern | Two lane standard | Two lane standard |
| Road class | Free-Flow | Free-Flow |
| Surface class | Secondary | Secondary |
| Pavement type | Primary | Primary |
| Carriageway width (m) | Surface Treatment on Granular Base | Surface Treatment on Granular Base |
|            | W1      | W2      |
|            | A       | 7.4     | 7.4     |
Table 4. Upgrading works detail (cont.)

| Section ID | A001-01 | A001-02 |
|------------|---------|---------|
| Section Name | Section One | Section Two |
| Speed limit (km/h) | B | 100 | 80 |
| | A | 120 | 100 |
| Upgraded SN (excluding subgrade) | 1.84 | 1.71 |
| Economic Cost | 306000 per km | 255000 per km |
| Financial Cost | 360000 per km | 300000 per km |

2.3. Project Alternative
When all candidate projects have been identified, HDM-4 can then be used to compare the life cycle performance and costs predicted under the existing regime of pavement management (i.e. the ‘without-project’ case) against the life cycle costs predicted for the periodic maintenance, road improvement or development alternative (i.e. the ‘with project’ case).

3. Result Analysis

3.1. Project Maintenance

3.1.1. Without project

![Figure 1. Annual average RUC section one without project](image1)

![Figure 2. Annual average RUC section two without project](image2)
By not upgrading the roadway to a bituminous pavement, the Annual average RUC per veh-km will be increase gradually parallel with the increasing of road life. From the graph we can see that this road will need to carry on a routine maintenance every three years to comply with the deterioration of the road. After maintenance conducted, the RUC will be decreased significantly but then it will be rapidly increase again due to road deterioration by the increasing volume of vehicle.

3.1.2. With project

![Annual Average Road User Cost per veh-km](image1)

**Figure 3.** Annual average RUC section one with project

![Annual Average Road User Cost per veh-km](image2)

**Figure 4.** Annual average RUC section two with project

As seen from figure 3 and 4 both section one and section two shows the same behaviour, after the project was being implemented the Annual average RUC per veh-km is decreasing significantly. For heavy vehicle categorize the RUC decrease as much as 0.9 Dollar per km, while for light vehicle category the decreasing of RUC is not as much as the heavy vehicle category which is about 0.2 US Dollar/ km.

After the year of project was being conducted, the average RUC of the overall vehicle slowly start to increase, however the value of RUC until the end years of planning will not exceed the value of RUC before the project is being implemented. In addition, further routine road maintenance will be not required.
3.2. Summary of Economic Indicator

Table 5. Economic Indicator

| Alternative          | RAC  | CAP  | Increase in Agency Costs (C) | Decrease in User Costs (B) | Net Exogenous Benefits (E) | (NPV = B+E-C) | NPV/Cost Ratio (NPV/RAC) | NPV/Cost Ratio (NPV/CAP) | IRR  |
|----------------------|------|------|-------------------------------|---------------------------|---------------------------|---------------|--------------------------|--------------------------|------|
| Without Project      | 1.822| 0.893| 0.000                         | 0.000                     | 0.000                     | 0.000         | 0.000                    | 0.000                    | 0.000|
| With Project         | 14.272| 14.161| 12.450                       | 20.053                    | 0.000                     | 7.603         | 0.533                    | 0.537                    | 17.6 |

With RAC = Present Value of Total Agency Costs
CAP = Present Value of Agency Capital Costs
NPV = Net Present Value
IRR = Internal Rate of Return

After define a series of treatment strategies, the optimum net present value (NPV) can be obtained. NPV is a method of appraising investment opportunities. The basic understanding of NPV is if the NPV is positive means that the project still has a value in the future. The economic summary indicates that With Project alternative giving a better investment opportunity at the end of analysis period in year 2038. At the beginning of analysis period, the Total Agency Cost (RAC) of With Project alternative is immensely high compare with without project alternative, consequently at the end of analysis period the Net Present Value which indicate the investment opportunities is higher than Without Project alternative. In addition, the Internal Rate of Return (IRR) of paved road also higher than the gravel road that is 17.6 % compared with 0.00.

The internal rate of return (IRR) of a particular investment is the discount rate that, when applied to its future cash flows, will produce an NPV of precisely zero. In essence, it represents the yield from an investment opportunity. In accordance of the statement, in means that the value of NPV of with project will remain positive although subjects to discount rate at 17.6 %.

4. Conclusion

The treatment standard to which roads are maintained will affect the future performance of the road and also the total road cost. Consequently, it is essential to observe the variation in cost and overall road performance with different treatment maintenance standard to decide which treatment standard is economically optimal and appropriate.

By compare the road works between with project alternative and without project, we can see that there is an immense difference on the work carried on and the financial economic cost. On the With Project alternative both for section one and section two, it will be upgrading works in the beginning of the year and there will only two maintenances that will be carried out during 20 year of the analysis period. However, by conducted upgrading and only two maintenances, this project requires high economical and financial cost that is 7,332,800.0 US Dollar and 8,716,000.0 US Dollar for section one and 9,512,400.0 US Dollar and 11,328,000.0 US Dollar for section two but mostly the cost will used to fund road upgrading.

In contrast, considering Without Project Alternative, maintenance is carried on every year including grading beside spot regrevelling, and gravel resurfacing will need to be conduct as much as 6 times during 2012 - 2031. We can see from the table that if compared by With Project alternative, this project expenditure is considering as a very low-cost project, both in economic and financial cost specifically 1,708,284.0 US Dollar and 2,033,477.1 US Dollar for section one and 2,620,615.5 US Dollar and 3,114,314.9 US Dollar for section two.

The alternatives project should be chosen based on the life cycle cost of maintenance and road user cost (RUC). Despite of the amount of cost that has to be incurred, although ‘with project’ alternative
spend much more than ‘without project’ alternative however ‘with project’ alternative can sustain the road performance better than without project alternative. In terms of RUC, ‘with project’ alternative also give the best result with very low RUC if compared with ‘without project’.

In conclusion, from two proposed alternatives, ‘with project’ alternative is the most appropriate project considering the number of maintenance will be carried out, overall road performance, RUC, and the values of NVP and IRR.

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