Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Determination of Impact of Maintenance on Traffic Volume Threshold for Upgrading of Low Volume Roads

Saroj Acharya [a]

[a] *Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal*
Corresponding Email: [a] ssaroj.ach@gmail.com, 073mstr262.saroj@pcampus.edu.np

Abstract

A good transport network plays a vital role in achieving economic success in modern economics. The rural roads connect the people of rural areas to their market centers and the administrative centers. Upgrading and maintaining these roads to all weather roads need huge resources. A proper economic decision tool is needed to mobilize the scare funds through prioritization of roads for upgrading and maintenance on the basis of their importance. The in-depth study on impact of maintenance on threshold for upgrading rural roads which we lack in context of Nepal will help concerned authority in planning the maintenance work on rural roads and decide the suitable time for upgrading of these roads.The HDM-4 is used as the tool to calculate the Net Present Value of a project alternative. The Net Present Value of a project alternative is the difference between the Present Value of Total Transportation Cost of base alternative and the project alternative. The traffic volume corresponding to the Zero Net Present Value gives the threshold value of the traffic volume for upgrading the road from base alternative to project alternative. The traffic threshold (ADT) for upgrading the earthen road to gravel road, DBST road and asphalt road is 50, 77 and 92 respectively for Ideal Maintenance Scenario and 48, 70 and 89 for Minimal Maintenance Scenario. Similarly, traffic threshold (ADT) for upgrading the gravel road to DBST road and asphalt road is 108 and 131 respectively for Ideal Maintenance Scenario and 80 and 105 for Minimal Maintenance Scenario.

Keywords

Rural roads, Road Upgrading, Road Maintenance, Economic Analysis, Threshold, Road User Cost, Vehicle Operating Cost, IRI

1. Introduction

The transport network ensures the connectivity within the country as well as with other countries by connecting people to jobs, linking products to markets, strengthening supply chain and logistics and fostering internal and external trade [1]. Out of 57,632.04 km of rural roads, only 3.5% is black toped standard, 22.2% is gravel standard and remaining 74.3% is earthen standard. Out of them, length of all weather road is only 25.7% roads[2]. These rural roads connect the people of rural areas to their market and the administrative centers. Therefore we need to upgrade these roads to make them all weather roads to ensure that the people living in rural parts of the country have excess to the market centers and administrative centers throughout the year. Upgrading and maintaining these roads to all weather roads need huge resources. Due to inadequacy of resources to upgrade all of these roads to all weather standard, we need a proper economic decision making tool to mobilize the scare funds through prioritization on the basis of importance of these roads. The traffic threshold for upgrading the road can be an important indicator for prioritization of roads. There is a trend to allocate a huge portion of budget towards construction of new roads and upgrading them to black top roads rather than maintenance of existing roads. It is partly due to the public demand for black top roads and partly due to lack of mindfulness among decision maker about the importance and benefit about the regular maintenance of existing roads. In lack of proper maintenance, these roads (mainly earthen and gravel roads) deteriorate and increase the vehicle operating cost. In long run, a huge fund is required for rehabilitation of these roads to make them suitable for vehicle operation. So, the periodic and recurrent maintenance can greatly reduce the vehicle operation and road user cost especially for unpaved roads [3]. If the benefit of regular maintenance work can be quantified, then it can support the allocation of economically justifiable fund for the maintenance of the rural roads.

2. Research Objectives

The main objective of this study is to determine the impact of road maintenance on traffic volume threshold for upgrading of low volume roads. In order to achieve the main objective the following sub objectives are set out:

- To determine the influence of road maintenance in vehicle operating cost.
- To determine the suitable pavement for a given traffic condition.
- To determine the threshold for upgrading of low volume roads with and without maintenance.

3. Literature Review

3.1 Introduction

Low volume rural roads are different from trunk roads in terms of construction and operation. As length of the road to be covered to serve same number of population is higher for rural roads than urban roads, the per capita cost of rural road is more than urban roads. In spite of having high per capita cost, government need to invest in rural roads for poverty reduction and improvement of access[4]. Traffic is one of the reasons for deterioration of road. The deterioration of the road increases the vehicle operation cost so road of needs the regular maintenance to maintain the desired level of service. The rate deterioration of road with increase of traffic is higher for unpaved road than paved roads ultimately causing the maintenance of unpaved roads costlier than paved roads. So, above certain traffic volume, upgrading of unpaved road to paved roads will be economically efficient than maintaining unpaved road.

3.2 Road Construction, Upgrading and Maintenance

Construction of new roads can have several reasons. It can be a result of increase in demand of existing roads, need for improving a regional and national connectivity or for a strategic need. The road infrastructure requires a huge investment for survey, design, land acquisition, road construction and maintenance. The rural roads are mostly constructed for improving the connectivity. These roads usually have very low traffic volume during the construction period so construction of low cost roads i.e. earthen, gravel standard is economically justifiable. As the economic activities increases with improvement in connectivity of rural area with other parts, the traffic volume increase. So, to address the increase in demand the rural roads are upgraded to better roads i.e. paved roads which reduces the vehicle operation cost, increases the level of service and road capacity.

Road maintenance is the series of interdependent activities carried out on and off the road surface with a view to preserve the assets and to maintain its serviceability. If more than 25 percentage of the road length need to be rebuilt it is considered as rehabilitation rather than maintenance. Based on the nature and timing of maintenance works maintenance work can be broadly grouped into three categories[5] i.e. Routine Maintenance, Periodic Maintenance, Urgent Maintenance.

Although rural roads are relatively cheap to construct but due to lack of timely maintenance and poor road condition, the vehicle operating cost and the risk of accident is high. The rate of deterioration of rural roads is high so after a certain period of start of deterioration, the rehabilitation or reconstruction is unavoidable. In order to avoid the huge cost of rehabilitation and reconstruction, there is an urgent need of a rational strategy for resource allocation for timely maintenance of rural roads based on the prioritization[6].

3.3 Pavement Deterioration

As stated in Discussion Paper on Road Pavement Management [7] the deterioration of pavement is continuous process irrespective of design and construction standards and is influenced by several factors such as environment(terrain), traffic(volume and axle load) and construction(design and construction standards and quality of materials and workmanship). The pavement deterioration reduces the serviceability of road and increases the road user cost and maintenance cost. The loss of serviceability increases the discomfort and travel time which further increases the road user cost. This increase in road user cost justifies the road agency's investment to minimize the deterioration. For traffic levels above 250 ADT, the vehicle operating costs constitute around 75% to 95% of total road transport cost [7].

As per ”Road Deterioration in Developing Countries” [8], a World Bank policy study, in absence of road maintenance unpaved roads deteriorate rapid but rather uniform rate throughout their life cycle. Meanwhile, paved roads when operated unmaintained deteriorate in a non liner pattern. The deterioration is low during the initial two thirds part of the life cycle. Beyond that period the deterioration is much more rapid causing the pavement to deteriorate from good condition to fair condition just within few years. Within next few years the pavement undergoes a radical structural failure[8]. During the initial phase maintaining paved roads in good condition requires fairly inexpensive routine maintenance. When pavement deteriorates to fair condition usually after half of its life cycle maintaining road to good condition requires a resurfacing incurring a moderate cost. Beyond initial two thirds part of the life cycle the pavement requires a huge cost for maintenance or even requires a reconstruction[8].

3.4 Pavement Condition Measurement Parameters

The road deterioration can be quantified by different measures of pavement condition like Surface roughness, Surface distress, Structural Capacity [7].Surface roughness which measures the irregularity on the pavement surface and expressed in terms of International Roughness Index (IRI) in meter/km. It will be related with the Vehicle Operation Cost (VOC) during the analysis as VOC increases with increase in surface roughness.

3.5 Economic Evaluation

Road economic evaluation is a process where the cost and benefits from a scheme are quantified over a evaluation period and evaluated using a common yardstick. It is also known as Benefit-Cost analysis [9]. The economic evaluation of road projects is basically a comparison of transport cost components calculated for at least two alternatives of road constructions, usually one being with project alternatives and another being without project alternatives[10]

3.5.1 Criteria for Upgrading and Prioritization

The economic evaluation for determination of criteria for investment for upgrading and maintenance of road measures the project benefits according to road user costs savings (consumer surplus method) or producer economic gains (producer surplus method). With the consumer surplus method, the project with the alternative (upgrading) is compared with the project without the alternative (keeping the road unsealed) according to the present value of road agency costs and road user costs over a certain period of evaluation at a given discount rate. The recommended alternative is the one with the lower present value of total transport costs (road agency plus road user costs). The results of an economic evaluation of whether unsealed roads should be upgraded are mainly a function of the investment and maintenance costs, the level of traffic on the road, road user costs, and the predicted road condition over time with and without the upgrade, which is a function of the level of maintenance applied. Traditionally, project alternatives are characterized by the initial investments.

3.5.2 Highway Development and Management Model (HDM-4)

Out of various tools for economic evaluation of road investments, Highway Development and Management Model (HDM-4) developed by International Study of Highway Development and Management Tools, present a good framework for economic evaluation of investment in road construction and maintenance [11]. This model is important tools for development of the economic and technical evaluation of road networks. Moreover, these systems incorporate performance models for bituminous, concrete and unsealed roads and the same needs to be calibrated according to the specific conditions of a country or region where they are to be used. The model HDM-4 needs to be adjusted by certain calibration factors in reference to the specific conditions of the country or region in order to use it for pavement management activities[12]. The direct influence of the initiation and progression of pavement distress processes makes it necessary to adequately adjust them to perform an accurate economic evaluation of the road studies. The road under evaluation is modelled using these parameters so as to represent the actual scenario. The result hugely depends upon the extent to which model represent the real scenario. The model is then evaluated under various scenarios to evaluate the performance of the road under such scenario.

4. Methodology

For the purpose of the research Armadi-Banau Road of Parbat District that is being upgraded by Rural Connectivity Improvement Project (RCIP) under Department of Local Infrastructure (DoLI) is the study area. HDM-4 requires a number of data to prepare a model to represent the actual field scenario and evaluate the performance of the model under different alternatives. The accuracy of model on representation of actual scenario depends on the accuracy and adequacy of data. The secondary data was obtained from the Detail Project Report of this road prepared by the project. This includes the alignment and geometry of the road, traffic data during the design, population served, economic status of the road users, CBR value of the subgrade etc. The primary data regarding the condition of road i.e. road roughness, rise and fall, length etc. was collected using the mobile application “Roadroid”. The data regarding the maintenance cost and the upgrading cost was obtained from the norms from Department of Roads (DoR) and DoLI. This includes the construction cost for graveling of road, construction of DBST and Asphalt Concrete and the cost of maintenance work in these roads. The data required for calculating the Vehicle operating cost was obtained from market survey.

4.1 Setting the Project Alternatives for Analysis

For the analysis of performance of road in different conditions, the following seven alternatives are formulated.

Table 1: Project Alternatives for Evaluation

Alt No.	Alternative Code	Initial Investment	Maintenance Policy
1	ETH-IM	Earthen Road	Ideal
2	GRA-MM	Gravel Road	Minimal
3	GRA-IM	Gravel Road	Ideal
4	DST-MM	DBST Road	Minimal
5	DST-IM	DBST Road	Ideal
6	AM-MM	Asphalt Road	Minimal
7	AM-IM	Asphalt Road	Ideal

The upgrading standards are defined based on the Nepal Roads Standards and Nepal Rural Road Standards.

4.2 Forecasting the Traffic Volume, Road Deterioration and Road Maintenance Frequency

The traffic growth rate was calculated using the traffic data during the design year (in DPR) and the present traffic data from field survey. The traffic volume is used to forecast the Road deterioration and represented in terms of International Roughness Index (IRI) which is used to determine the frequency of maintenance. The minimal maintenance include only the routine maintenance. The ideal maintenance policy for gravel road includes annual maintenance, one heavy grading per year, and re-graveling when the gravel thickness reaches 50 mm. The ideal maintenance policy for DBST road includes annual routine maintenance, patching of all potholes, resealing of the road when the area of the damaged surface reaches 20% and the roughness reaches an international roughness index (IRI) of 6.0 m/km, and placement of a 50-mm asphalt mix overlay when the roughness reaches an IRI of 6.5 m/km. The ideal maintenance policy for asphalt concrete includes annual routine maintenance, patching of all potholes, and placement of a 50-mm overlay when the roughness reaches an IRI of 4.0 m/km [3].

The deterioration behavior of various road surfaces is different. The measurement of road roughness is a useful tool for tracking the deterioration of roads. The road roughness is usually expressed in terms of International Roughness Index (IRI). As measurement of IRI is difficult for all roads, the IRI of the road is estimated using a mobile application named “Roadroid” which is one of the widely used application for estimation and tacking of road condition[13, 14]. The Figure 1 shows the deterioration of DBST road in terms of IRI estimated by Roadroid and forecasted by HDM-4.

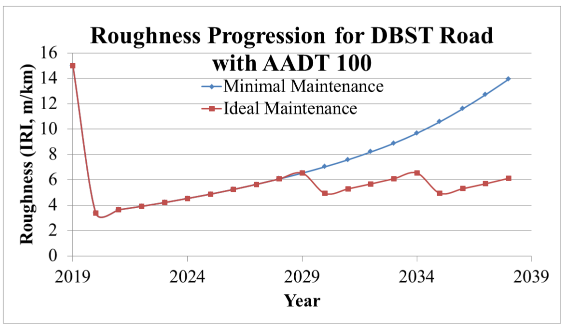

Figure 1: Roughness Progression for DBST Road with AADT 100

Figure 1 shows that the Ideal Maintenance reduces average roughness of the road by 26 % in comparison with Minimal Maintenance.

4.3 Calculating Present Value of Total Transportation Cost

The total transportation cost is calculated as the sum of the road user cost and road agency cost. The total road user cost comprises of vehicle operating cost and travel time cost of both motorized transport and non-motorised transport and accident cost [15]

Out of these components, motorised transport (MT) vehicle operating cost and travel time cost only are taken into consideration due to the limitation of availability of accident data and non-motorised traffic data. The motorised transport vehicle operation cost and travel time cost depend largely on road roughness and the geometric characteristics of the road. Travel Time Cost is calculated based on the passenger time cost (Rs/ passenger-hr), cargo holding time cost (Rs/veh-hr) number of passengers, number of vehicles and total travel time. The road agency cost includes initial investment in upgrading and the present value of future maintenance works which is calculated based on the district rates and work norms prepared by DoR and DoLI.

The present value of road agency cost, present value of road user cost and present value of Total Transportation cost is calculated using HDM-4 for present traffic volume of 83 AADT and different traffic volume from 30 AADT to 500 AADT for all alternatives is presented in Table 2, 3 and 4.

Table 2: Present Value of Road Agency Cost

Alt	AADT					
No.	83	30	100	200	300	500
1	0.003	0.003	0.003	0.003	0.003	0.003
2	0.427	0.427	0.427	0.427	0.427	0.427
3	0.724	0.641	0.728	0.83	0.94	1.043
4	1.339	1.339	1.339	1.339	1.339	1.339
5	1.586	1.553	1.594	1.679	1.702	1.818
6	1.873	1.873	1.873	1.873	1.873	1.873
7	2.032	2.017	2.032	2.093	2.116	2.13

In Table 2 we observe that, the Ideal maintenance increases the present value of road agency cost. The percentage of increase is higher for high traffic volume.

Table 3: Present Value of Road User Cost

Alt	AADT					
No.	83	30	100	200	300	500
1	5.09	1.53	5.37	11.04	16.79	28.39
2	4.34	1.23	4.60	9.98	15.62	27.11
3	3.83	1.13	4.06	8.56	13.23	23.68
4	3.23	1.01	3.41	6.96	10.61	18.13
5	3.12	0.99	3.28	6.59	9.92	16.60
6	3.10	0.97	3.27	6.58	9.94	16.84
7	3.01	0.95	3.17	6.36	9.56	16.01

Table 3 shows that, the Ideal maintenance decreases the present value of road agency cost. The percentage of decrease is higher for high traffic volume.

Table 4: Present Value of Total Transport Cost

Alt	AADT					
No.	83	30	100	200	300	500
1	5.10	1.53	5.38	11.05	16.79	28.39
2	4.77	1.65	5.03	10.41	16.05	27.54
3	4.56	1.77	4.78	9.39	14.17	24.72
4	4.57	2.35	4.75	8.30	11.95	19.47
5	4.71	2.54	4.88	8.27	11.62	18.42
6	4.97	2.85	5.14	8.45	11.81	18.71
7	5.05	2.97	5.20	8.46	11.68	18.14

Table 4 shows that, the Ideal maintenance increases the present value of total transportation cost of vary low volume roads (30 AADT) and decreases the present value of total transportation cost of high volume roads (300 or higher AADT)

The total transportation cost of each alternative is compared for each traffic volume to determine the best alternative for each traffic volume. Net Present Value (NPV) with current pavement condition as base alternative and desired pavement as other alternative is determined as change in Present value of total transportation cost for each traffic condition. The positive NPV justifies the investment. The traffic volume corresponding to 0 NPV represents the threshold for upgrading the road from base alternative to desired alternative.

5. Data Analysis and Results

Based on the Table 4 we can plot the graphs for the total transportation cost for different pavement alternative with given traffic volume. Figure 2 shows the total transportation cost of different road alternatives with ADT 83 i.e. the present traffic condition of the road under evaluation.

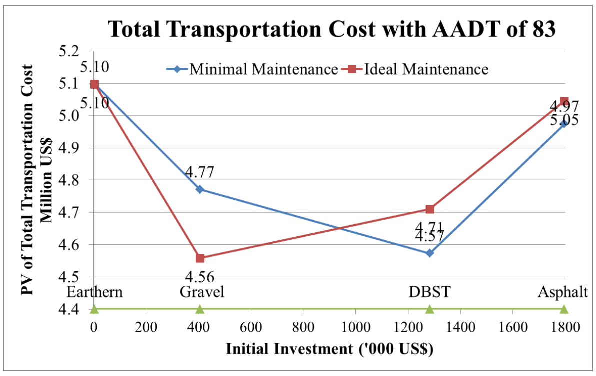

Figure 2: Total Transportation Cost with AADT of 83

Based on the Figure 2, Gravel surface with Ideal maintenance is the best option with lowest total transport cost and DBST surface with Minimal maintenance is the second best alternative.

Similarly, the Present Value of Total Transportation in Table 4 can be plotted to determine the road surface with lowest total transportation cost which is the most suitable alternative for given traffic. The best road surface alternative for given traffic volume based on the total transportation cost is summarized in Table 5.

Table 5: Alternative with lowest Transportation Cost

AADT	Maintenance Scenario		
	Overall	Ideal	Minimal
83	Gravel-IM	Gravel	DBST
30	Earthen-MM	Earthen	Earthen
100	DBST-MM	Gravel	DBST
200	DBST-IM	DBST	DBST
300	DBST-IM	DBST	Asphalt
500	Asphalt-IM	Asphalt	Asphalt

5.1 Calculation of Threshold Traffic Needed to Justify the Upgrading

The Net Present worth for an investment i.e. upgrading is computed for all project alternatives through the difference between Present value of base alternative and project alternative. The present condition of the road (say gravel road) was taken as base alternative and the intended upgrade is taken as project alternative. This computation is carried out for both conditions i.e. with Ideal maintenance and with Minimal maintenance. The alternative with positive Net Present Value is economically justified for given traffic volume.

The net present value of the project alternatives is calculated considering the Earthen road as base alternative as presented in Table 7 for Ideal Maintenance scenario and Table 6 for Minimal Maintenance scenario.

Table 6: Net Present Value for Minimal Maintenance Scenario

Alternative	AADT				
	30	100	200	300	500
Earthern	0.00	0.00	0.00	0.00	0.00
Gravel	-0.13	0.35	0.64	0.75	0.85
DBST	-0.82	0.63	2.75	4.85	8.93
Asphalt	-1.32	0.24	2.60	4.98	9.68

Table 7: Net Present Value for Ideal Maintenance Scenario

Alternative	AADT				
	30	100	200	300	500
Earthern	0.00	0.00	0.00	0.00	0.00
Gravel	-0.24	0.59	1.66	2.62	3.67
DBST	-1.01	0.50	2.77	5.17	9.98
Asphalt	-1.44	0.17	2.59	5.11	10.25

The project alternative with positive net present Value is considered to be economically justifiable. Table 6 and 7 show that it is not economically justifiable to upgrade the earthen road to gravel or black top for ADT of 30 or below but it is economically justifiable to upgrade to gravel or black top for ADT 100 or above in both minimal and nominal maintenance scenario. Figure 3 and 4 presents the graph of the Net present Value as of Table 6 and 7.

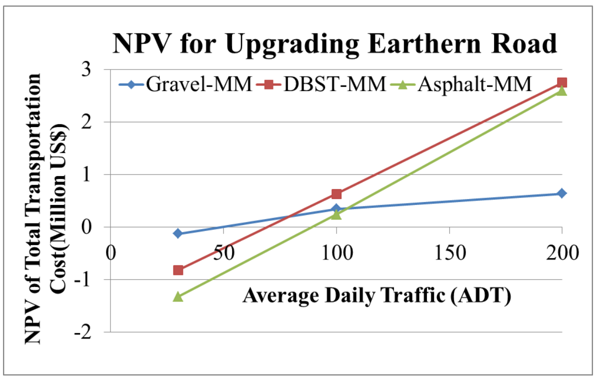

Figure 3: NPV for Upgrading Earthen Road for Minimal Maintenance

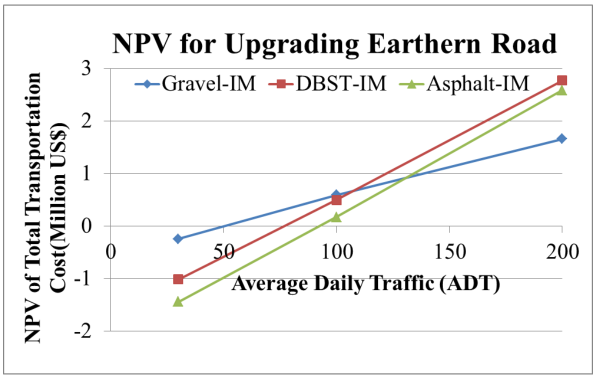

Figure 4: NPV for Upgrading Earthen Road for Ideal Maintenance

The AADT corresponding to NPV=0 represents the traffic threshold needed to economically justify the upgrading from base alternative to the project alternative. Figure 3 and 4 shows that the traffic threshold (i.e. AADT for NPV=0)that economically justifies the upgrading is as presented in Table 8.

Table 8: Traffic Threshold to Justify the Upgrading of Earthen Road

Project Alternative	Ideal Maintenance	Minimal Maintenance
Upgrading to Gravel	50	48
Upgrading to DBST	77	70
Upgrading to Asphalt	92	89

Table 8 shows that traffic threshold for upgrading the earthen road is higher for ideal maintenance scenario than for minimal maintenance scenario. Similarly, the net present value of the project alternatives is calculated considering the Gravel road as base alternative as presented in Table 9 for Minimal Maintenance scenario and Table 10 for Ideal Maintenance scenario.

Table 9: Net Present Value for Minimal Maintenance Scenario

Alternative	AADT				
	30	100	200	300	500
Gravel	0.00	0.00	0.00	0.00	0.00
DBST	-0.69	0.28	2.11	4.10	8.07
Asphalt	-1.19	-0.11	1.96	4.24	8.83

Table 10: Net Present Value for Ideal Maintenance Scenario

Alternative	AADT				
	30	100	200	300	500
Gravel	0.00	0.00	0.00	0.00	0.00
DBST	-0.77	-0.09	1.11	2.55	6.31
Asphalt	-1.20	-0.42	0.93	2.50	6.58

Table 9 and 10 show that it is not economically justifiable to upgrade the gravel road to DBST for ADT of 30 or below but it is economically justifiable to upgrade to gravel or DBST for ADT 100 or above for Minimal Maintenance scenario.
Similarly, it is not economically justifiable to upgrade the gravel road to DBST for ADT of 100 or below but it is economically justifiable to upgrade to gravel or DBST for ADT 200 or above for Ideal Maintenance scenario.On plotting the Table 9 and 10, the traffic threshold (i.e. AADT for NPV=0) that economically justifies the upgrading is determined as presented in Table 11.

Table 11: Traffic Threshold to Justify the Upgrading of Gravel Road

Project Alternative	Ideal Maintenance	Minimal Maintenance
Upgrading to DBST	108	80
Upgrading to Asphalt	131	105

Again, the net present value of the project alternatives is calculated considering the DBST road as base alternative as presented in Table 12 for Minimal Maintenance scenario and Table able 13 for Ideal Maintenance scenario.

Table 12: Net Present Value for Minimal Maintenance Scenario

Alternative	AADT				
	30	100	200	300	500
DBST	0.00	0.00	0.00	0.00	0.00
Asphalt	-0.50	-0.39	-0.15	0.14	0.76

Table 13: Net Present Value for Ideal Maintenance Scenario

Alternative	AADT				
	30	100	200	300	500
DBST	0.00	0.00	0.00	0.00	0.00
Asphalt	-0.43	-0.33	-0.18	-0.05	0.27

Table 12 and 13 show that it is not economically justifiable to upgrade the DBST road to Asphalt for ADT of 200 or below but it is economically justifiable to upgrade to Asphalt for ADT 300 or above for Minimal Maintenance scenario.
Similarly, it is not economically justifiable to upgrade the DBST road to Asphalt for ADT of 300 or below but it is economically justifiable to upgrade to Asphalt for ADT 500 or above for Ideal Maintenance scenario. On plotting the Table 12 and 13, the traffic threshold (i.e. AADT for NPV=0) that economically justifies the upgrading is determined as presented in Table 14.

Table 14: Traffic Threshold to Justify the Upgrading of DBST Road

Project Alternative	Ideal Maintenance	Minimal Maintenance
Upgrading to Asphalt	334	253

6. Conclusions

The road deterioration behaviours of different road pavement types are different and are affected differently by maintenance work. Maintenance reduces the roughness ofroads, which reduces road user costs that, influences the economic justification of proposed investments. Comparison of the investments in a given pavement type with ideal and minimal maintenance shows that ideal maintenance decreases the present value of total transport costs for gravel roads under any trafficlevel, showing that proper maintenance, is always economically justified for gravel roads. For bituminous roads, proper maintenance is justified for traffic volume higher than 300 AADT.
The traffic needed to justify investment in an upgrade also depends on the maintenance standard over the evaluation period. The result of this evaluation shows that the traffic needed to justify investment increases if proper maintenance is ensured both before and after upgrade. In other words, ensuring a proper maintenance will increase the threshold of traffic volume for upgrading a road surface.

References

[1] Rod Eddington and Rod Eddington. *Main report: transport's role in sustaining the UK's productivity and competiveness*. Number Rod Eddington ; 1 in The Eddington transport study. The Stationery Off, Norwich, 2006. OCLC: 255542831.

[2] Government of Nepal DoLIDAR. Statistics of Local Road Network (SLRN), 2016.

[3] Rodrigo Archondo-Callao. Maintenance Impact on Economic Evaluation of Upgrading Unsealed Roads. *Transportation Research Record: Journal of the Transportation Research Board*, 2203(1):151–159, January 2011.

[4] Sahadev Bahadur Bhandari, Padma Bahadur Shahi, and Rabindra Nath Shrestha. RANKING RURAL ROAD PROJECTS: WEIGHTING DIFFERENT EVALUATION CRITERIA WITH A FOCUS ON THE CASE OF NEPAL. page 23, 2016.

[5] Sally Burningham and Natalya Stankevich. Why Road Maintenance is Important and How to Get It Done. *World Bank*, page 10, 2005.

[6] Agarwal P.K., A.B. Khan, and S. Choudhary. A Rational Strategy for Resource Allocation for Rural Road Maintenance. *Transportation Research Procedia*, 25:2195–2207, 2017.

[7] DoR MRCU. Road pavement Management, 1995.

[8] Clell Harral and Asif Faiz. Road deterioration in developing countries : causes and remedies. (13370):1–76, October 1988.

[9] IRC IRC. Manual on Economic Evaluation of Highway Projects in India, 2009.

[10] H. A. Adler. ECONOMIC APPRAISAL OF TRANSPORT PROJECTS: A MANUAL WITH CASE STUDIES. 1971.

[11] A. Veeraragavan and K. B. Rathnakara Reddy. Application of Highway Development and Management Tool for Low-Volume Roads. *Transportation Research Record: Journal of the Transportation Research Board*, 1819(1):24–29, January 2003.

[12] Dattatraya Tukaram Thube. Highway Development and Management Model (HDM-4): calibration and adoption for low-volume roads in local conditions. *International Journal of Pavement Engineering*, 14(1):50–59, January 2013.

[13] Myles Johnston. USING CELL-PHONES TO MONITOR ROAD ROUGHNESS. page 10, 2013.

[14] Deshan Gamage, H. R. Pasindu, and Saman Bandara. Pavement Roughness Evaluation Method for Low Volume Roads. In *Proceedings of the Eighth International Conference on Maintenance and Rehabilitation of Pavements*, pages 976–985. Research Publishing Services, 2016.

[15] Henry G R Kerali. Volume 1 : Overview of HDM-4. *The World Road Association (PIARC)*, page 53, 2000.