Demonstration of HDM-4 in Evaluating Different Investment Alternatives for Unpaved Road

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Abstract**:** ***In the context of under developing countries like Afghanistan, poverty can be reduced by proper management and effective use of infrastructure budget, and provision of labor-intensive construction projects. The labor-intensive works approach can bolster livelihoods in the immediate term, create new small businesses in road maintenance and works, encourage workers to save and invest wages in other kinds of new micro-enterprises, and improve critical road infrastructure to sustained economic growth. In this study, the use of the HDM-4 model is demonstrated in defining the road improvement and maintenance works and selection of optimum maintenance and rehabilitation strategies available for the road sector under constrained budget available for the road sectors in Afghanistan. This study presents the economic analysis and justification of upgrading an existing engineered gravel road to a paved standard evaluating 8 different investment options. The existing road is 22.02 km long and passes through hilly topography.***

Keywords**: labor-intensive, HDM-4, constrained budget, investment options.**

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I. INTRODUCTION

Afghanistan is a landlocked mountainous country with plains in the north and southwest, about 70% of the territory of Afghanistan is occupied by mountains. Being a landlocked country; the country must depend mainly on Road transport for the export and import of goods to and from foreign countries. Transportation is the backbone of the development of the country. To maintain a well-organized transportation system and deliver the infrastructure necessary for economic development poverty alleviation and growth, road sector funding must be used effectively and efficiently. Pavement Maintenance Management System (PMMS) provides valuable information to carry out performance analysis, finding maintenance and rehabilitation requirements, establish priorities, and allocate funding wisely. Therefore, it is important to utilize road funding accurately and objectively.

Looking to the current Strategic Road Network (SRN) condition of Afghanistan, a huge part of the road network consists of unpaved roads. Furthermore, 60+% of the existing road network is in fair to a poor condition where 80% of them are unpaved roads. This not only increases the overall Transport Cost and prone high risk of safety concerns for the users, but it has also made it difficult for road engineers in Afghanistan to come up with optimum and sustainable maintenance strategies to overcome the addressed issues. Knowing the fact that unpaved roads deteriorate faster compared to paved standard roads the road agency needs a huge amount of budget to maintain the unpaved roads into a user-defined performance level. On other hand, the unavailability of a sufficient budget for maintenance works and the principal causes of road deterioration are left uninvestigated due to lack of data on the design, construction, and maintenance aspects of pavements.

Therefore, the Ministry of Public Works (MoPW) has to use some sort of Highway Development Model to address this issue in a detailed and systematic approach and evaluate it technically and economically. Hence, the demonstration of HDM-4 in the above-mentioned issue would help the engineers and road agency to a greater extent.

II. LITERATURE REVIEW

A. Paterson, W. D. (1987)

Deterioration and Maintenance of Unpaved Roads: Models of Unevenness and Material Loss. The research discusses the observed models of deterioration for the management of unpaved roads that have been established. Consecutive cycles of unevenness/roughness development and regrading are represented as a cyclic process reaching a steady-state pattern. One of its models anticipates the minimum, maximum, and average roughness as functions of road gradient, traffic volumes, degree of curvature, and the interval between gradings. In the second model. the rate by which the gravel losses are anticipated from similar variables. Both were calculated from extensive data collected in Brazil, and both are then compared with the data from other countries in Africa and South and North America, showing a good degree of transferability.

B. Sunanda Dissanayake, Ph.D., P.E., Himanshu S. Patel

In this paper, General guidelines were developed using the MCA method to reach the objectives of the study. The key factors for the decision-makers regarding paving were identified as agency cost, safety, Vehicle Operating Cost (VOC), traffic volume, road utilization, and public preference. The multi-criteria assessment method contains calculating the weights of the factors important for decision, finding the respective scaled values for each factor for paved and gravel surfaces, and ultimately calculating the final score gained by paved and unpaved pavement types.

C. Dr. Mir Shabbar Ali, Karam-un-Nisa Choudhary

Effect of Pavement condition on Traffic performance. Deterioration and unevenness of pavements have a high effect on traffic performance. Maintenance, rehabilitation, and preventive works of these pavements to the required level of serviceability and to control the traffic speed is one of the biggest problems faced by pavement engineers, government, and administration in the highway sector. Pavement Condition Index (PCI), has been widely used to give a responsive maintenance strategy for the existing pavements.

D. Zegeer, Stewart, Council, & Neuman, 1994

This study was done on a sample of around 5,000 miles of paved two-lane rural roads in seven states such as Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia. This study reached the roads with traffic volumes less than 2,000 V/day as low volume roads and predicted a crash rate of 3.5 per million vehicle miles traveled on LV paved roads compared to a crash rate of 2.4 per million on all high-volume roads. The study found that fixed-object crashes, rollover crashes, and other run-off-road crashes were more common on Low Volume Roads (LVRs). The study compared crash rates on paved roads and unpaved roads for three Average Daily Traffic ADT groups: ADT less than 250 VPD, ADT between 250 VPD and 400 VPD, and ADT greater than 400 VPD. The 250–400 VPD ADT group and the group with ADT greater than 400 VPD were finally combined due to the small sample size in the latter group.

III. Methodology

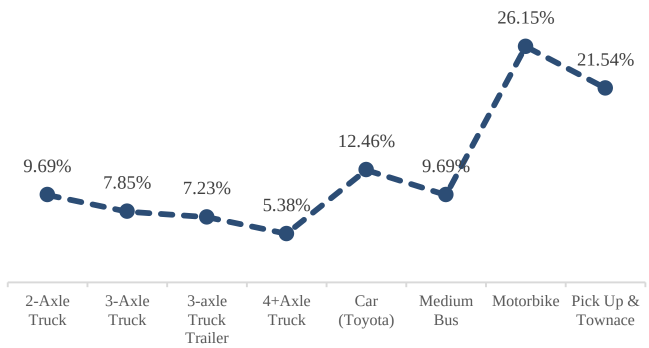
After problem identification, and the literature review in similar studies the revision of the study area profile and data collection is carried out at the candidate road location. Once data is successfully collected, the next step is to verify and validate the data. The data is refined and configured to be used in Highway Development and Management Model 4 (HDM-4) for economic analysis. For analysis, the following steps are considered.

1. Inventory and condition survey of the existing engineered gravel road.
2. Finding the existing traffic volume and percentage of the different fleet along with the traffic growth.
3. Introduction of various investment options in terms of keeping the road unpaved and finding the work's effect of different maintenance strategies with no improvement; and then provision of different improvement standards and prediction of traffic performance.
4. To find both cost and benefit components to get NPV, EIRR, and CB.
5. Perform sensitivity analysis for 25% increase in cost and 25% decrease in AADT.

A. Road Condition and Traffic Survey:

By performing the inventory and road condition survey at site by visual inspection the following information illustrated in Table II is used in HDM-4. For the road condition survey, the details received from the site are cross-checked with the Road Deterioration Model for unpaved roads using HDM relations from the actual on-ground practices for the candidate roads. The information received from the site and the model have very little to negligible differences that can be used for comparative studies in the HDM-4 model.

TABLE I. SHARE OF DIFFERENT VEHICLES TYPE (2020)



B. Road Section Characteristics of the Candidate Road

The road section characteristics of the candidate road are tabulated in the table below to perform economic analysis through HDM-4.

TABLE II. ROAD SECTION CHARACTERISTICS

Road Name; Survey Year	**Kunar to Nuristan; 2020**
Length (km); Traffic Volume	22.02; 650 AADT
C/way width (m)	5.0
Shoulder width (m)	1m on each side
Rise + Fall (m/km)	15
No. of Rise Plus Fall (no/km)	2
Superelevation (%)	3
Avg. Horizontal Curvature	75(deg/km)
Speed limit (kph)	80
Speed enforcement	1.1
Altitude (m)	1942
Subgrade material type	GC
Compaction method	Mechanical
Recent Gravel Thickness	170 mm
Roughness (IRI)	7

C. Work Items For Un-Paved Section

The following work standards are considered for unpaved roads.

- Routine Maintenance for the unpaved road; this work standard will be considered as the investment option where the road will not be upgraded to paved standard with annual intervention in HDM-4.
- Grading with different intervals; this work standard will be considered in supplement to the above RM with the intervention of different intervals i.e., 30, 60, and 90 days while keeping the road in unpaved standards.
- Re-gravelling as condition responsive treatment; this work standard will be considered in supplement to the above two work standards with an intervention of when the gravel thickness falls <25mm to a final thickness of 200mm.

D. Work Items for Paved Section

Comparing the different maintenance works for the unpaved road to find the optimum maintenance work while keeping the road unpaved the following work standards will be considered for upgrading the candidate road to a paved standard.

- Miscellaneous Routine Maintenance for paved section; this work standard will be considered after upgrading the candidate road to paved standard with annual intervention.
- 100% patching of potholes annually; this work standard along with the above RM will be considered for the paved section with condition responsive intervention or when the number of potholes > 2/km.
- Resealing of all cracks as condition responsive treatment; this work standard along with the above two work standards will be considered whenever the total damaged area >= 30% of the entire road section.
- 40mm overlay @ IRI – 5.0; finally, the last work standard for the paved section is considered an overlay with condition responsive treatment whenever the IRI of the road section falls above 5.

E. Improvement Standards Considered for Evaluation purpose

Apart from the maintenance standards considered for evaluation purposes the following improvement standards are also considered to check the economic viability of the candidate for an upgrade.

- Pave with 25 mm DBST on 150 mm crushed stone base and 150 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and reseal (25 mm DBST) wherever total damaged area (all cracks) exceeds 30%. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat)
- Pave with 50 mm AC on 150 mm crushed stone base and 150 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and overlay with 40 mm AC wherever IRI is > or = 5.0. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat)
- Pave with 50 mm AC on 200 mm crushed stone base and 200 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and overlay with 40 mm AC wherever IRI is > or = 5.0. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat)
- Pave with 100 mm AC on 200 mm crushed stone base and 200 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and overlay with 40 mm AC wherever IRI is > or = 5.0. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat)

IV. Summary of Investment Alternatives

The candidate road was evaluated with the eight investment alternatives described below and Alternatives 2 – 7 were compared against the base Alternative 1 which essentially comprises of grading the gravel road twice a year and re-graveling to final 200mm thickness whenever the gravel thickness falls below 25 mm; plus routine maintenance.

1. <u>Base Alternative (GR@180)</u>: Grading twice a year (@182 days interval) and re-graveling (200mm final) whenever the surface thickness fell below 25 mm plus routine maintenance (unpaved)
2. <u>Alternative 2 (GR@30)</u>: Grading once a month (@30 days interval) and re-graveling (200mm final) whenever the surface thickness fell below 25 mm plus routine maintenance (unpaved)
3. <u>Alternative 3 (GR@60)</u>: Grading every two months (@60 days interval) and re-graveling (200mm final) whenever the surface thickness fell below 25 mm plus routine maintenance (unpaved)
4. <u>Alternative 4 (GR@90)</u>: Grading once in three months (@90 days interval) and re-graveling (200mm final) whenever the surface thickness fell below 25 mm plus routine maintenance (unpaved)
5. <u>Alternative 5 (Pave with DBST)</u>: Pave with 25 mm DBST on 150 mm crushed stone base and 150 mm granular sub-base, followed by annual routine maintenance (paved) plus annual

patching of 100% of potholes when the number of potholes is > or = 2/km and reseal (25 mm DBST) wherever total damaged area (all cracks) exceeds 30%. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat).

6. Alternative 6 (Pave with Low Standard AC): Pave with 50 mm AC on 150 mm crushed stone base and 150 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and overlay with 40 mm AC wherever IRI is > or = 5.0. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat)

7. Alternative 7 (Pave with Medium Standard AC): Pave with 50 mm AC on 200 mm crushed stone base and 200 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and overlay with 40 mm AC wherever IRI is > or = 5.0. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat).

8. Alternative 8 (Pave with High Standard AC): Pave with 100 mm AC on 200 mm crushed stone base and 200 mm granular sub-base, followed by annual routine maintenance (paved) plus annual patching of 100% of potholes when the number of potholes is > or = 2/km and overlay with 40 mm AC wherever IRI is > or = 5.0. The width and geometric characteristics are as per the terrain (Mountainous, hilly, flat)

V. Conclusion & Results

The analysis period was taken 17 years to allow 15 years of pavement performance after the construction period of two years.

The results show that maintaining the road as gravel roads with such high volumes is much more expensive in economic terms compared to paving because of the frequent grading and re-graveling needed to keep the road in reasonable condition. However, the most cost-effective alternative within the gravel road maintenance options is to grade the roads at least every 60 days two months. With this alternative, the roughness of the road is generally kept below 10 IRI for the entire analysis period. The figure below illustrates the outcome of the economic evaluation and road roughness of candidate road for the analysis period considered.

FIGURE 1 BASE SCENARIO ROAD ROUGHNESS/YEAR

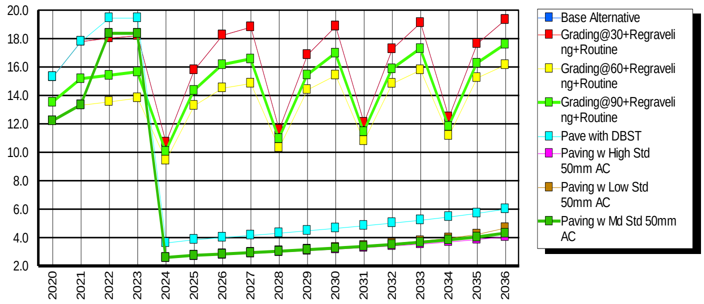


TABLE III. BASE SCENARIO ECONOMIC INDICATORS

Alternative	NPV	NPV/C	IRR
Base Alternative	0.000	0.000	0.000
Grading@30+Regraveling+Routine	0.000	0.000	No Solution
Grading@60+Regraveling+Routine	2.054	0.886	No Solution
Grading@90+Regraveling+Routine	1.354	0.584	No Solution
Pave with DBST	5.424	1.613	30.0 (1)
Paving w High Std 50mm AC	5.566	1.375	28.9 (2)
Paving w Low Std 50mm AC	6.373	1.890	35.8 (2)
Paving w Md Std 50mm AC	6.057	1.663	32.7 (2)

A. *Sensitivity Analysis*

A sensitivity analysis was performed with a 25% reduction in the traffic volumes along with sensitivity analysis assuming a 25% increase in cost. As can be seen from the table below, in all cases of the road evaluated, paving is justified, wherein the NPV at 12% discount rate is positive, even with a 25% reduction in the current traffic volumes. As shown above, three basic options for paving (DBST, Medium Standard AC, and High Standard AC) and related pavement designs were evaluated along with the alternative of maintaining the unpaved road as a gravel road with different frequencies of grading and re-graveling the surface whenever its thickness fell below 25 mm.

FIGURE 2 SENSITIVITY SCENARIO ROUGHNESS/YEAR

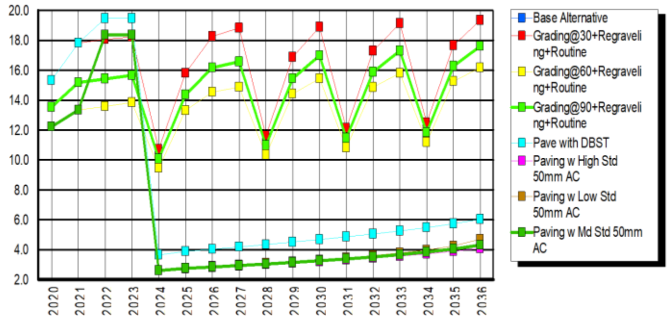


TABLE IV. SENSITIVITY SCENARIO ECONOMIC INDICATORS

Alternative	NPV	NPV/C	IRR
Base Alternative	0.000	0.000	0.000
Grading@30+Regraveling+Routine	0.000	0.000	No Sol
Grading@60+Regraveling+Routine	2.543	0.842	No Sol
Grading@90+Regraveling+Routine	1.586	0.525	No Sol
Pave with DBST	8.164	2.427	43.0 (1)
Paving w High Std 50mm AC	8.837	2.184	49.8 (2)
Paving w Low Std 50mm AC	9.204	2.540	81.3 (2)
Paving w Md Std 50mm AC	9.220	2.531	60.9 (2)

The tables clearly show the superiority of the paving options in reducing and sustaining the average roughness on the roads along with the required periodic maintenance during the analysis period (15 years after 2 years of construction period). Due to the high levels of roughness, the NPVs for keeping the roads as gravel roads in all cases is much lower than for the paving alternatives where the roughness remains below 6 IRI during almost the entire analysis period.

Going by the highest NPV in the set of alternatives for each road, the ideal investment is to pave the roads with a low standard AC design.

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