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Feasibility Investigation of Upgrading Gravel Road to Otta Seal Surface: an Economic Analysis Approach

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Abstract
The Norwegian Road Authorities desired that a surface treatment be cost-effective to provide a faster return on investment, perform (as perceived by the road user) in a manner similar to conventional bituminous surfacing, and comply with the following requirements: • Be cheap and easy to implement • Utilize locally-available aggregates • Be impervious to prevent water incursion into moisture-susceptible base material • Be very flexible, durable, and easy to maintain.

Such a bituminous surface treatment, referred to as in 1963, and initial field trials were carried out during 1963-1965 in the Otta Valley, Norway. Although Nordic countries, Asia, Africa, New Zealand, and South America have continued to see increasing use of Otta seal (*1*), its use in the US is currently rather limited due to a lack of knowledge and of the empirical design approach associated with this technique that requires evaluation of trial or demonstration sections before deployment. Minnesota, South Dakota, and Iowa are the only states that have currently completed Otta seal projects in the US, and a summary discussion of MN's and SD's experiences with Otta seal is given in this section (*2, 3*).

In this paper, the life cycle cost of surfacing and maintaining an upgraded gravel road to an Otta seal coated surface over a one-mile generic road in Minnesota was evaluated through deterministic and stochastic life-cycle cost analysis (LCCA). Since various road and highway agencies in Minnesota have implemented Otta seal and provided access to the historical cost records needed to complete this study, Minnesota was chosen for a case study for conducting the analysis.

Disciplines
Civil Engineering | Transportation Engineering

Comments
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INTRODUCTION

The Norwegian Road Authorities desired that a surface treatment be cost-effective to provide a faster return on investment, perform (as perceived by the road user) in a manner similar to conventional bituminous surfacing, and comply with the following requirements:

- Be cheap and easy to implement
- Utilize locally-available aggregates
- Be impervious to prevent water incursion into moisture-susceptible base material
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Such a bituminous surface treatment, referred to as in 1963, and initial field trials were carried out during 1963-1965 in the Otta Valley, Norway. Although Nordic countries, Asia, Africa, New Zealand, and South America have continued to see increasing use of Otta seal (*1*), its use in the US is currently rather limited due to a lack of knowledge and of the empirical design approach associated with this technique that requires evaluation of trial or demonstration sections before deployment. Minnesota, South Dakota, and Iowa are the only states that have currently completed Otta seal projects in the US, and a summary discussion of MN's and SD's experiences with Otta seal is given in this section (*2*, *3*).
In this paper, the life cycle cost of surfacing and maintaining an upgraded gravel road to an Otta seal coated surface over a one-mile generic road in Minnesota was evaluated through deterministic and stochastic life-cycle cost analysis (LCCA). Since various road and highway agencies in Minnesota have implemented Otta seal and provided access to the historical cost records needed to complete this study, Minnesota was chosen for a case study for conducting the analysis.

Previous studies have also shown that annual maintenance costs for a gravel road increases as the annual average daily traffic increases (*4*). Moreover, because there is a general trend toward increased traffic volume, especially in urban areas, further studies were recommended to determine the best times for upgrading roads to bituminous surface treatment (BST) considering traffic volume (*5*). Therefore, the second part of this study, a traffic-volume based economic analysis, was conducted on two gravel roads in two counties (i.e. Goodhue and Winona) in Minnesota exhibiting different annual daily traffic (ADT) and AADT patterns to evaluate cost-per-mile trends for gravel roads as traffic increases.

OVERALL DESCRIPTIONS OF ANALYSIS APPROACH

FHWA describes life-cycle cost analysis for highway projects as "an analysis technique … to evaluate the overall long-term economic efficiency between competing alternative investment options" (*6*). The basic model outlined by FHWA will be used to conduct the life-cycle cost analysis for this study. In addition to an FHWA life-cycle cost analysis approach, a deterministic method, stochastic Life-Cycle Cost Analysis (LCCA), was also employed to compare competing design alternatives. The specific approach for this study utilizes equivalent uniform annual cost (EUAC) analysis, permitting elimination of many assumptions required when using the more common, and more problematic, net present worth LCCA (*7*) . Deterministic EUAC, the traditional method used for decision-making in pavement management, involves using point estimates that result in a single output value (*8–13*). The outcome of a deterministic LCCA depends on numerous estimates, forecasts, assumptions, and approximations, with each factor having some potential to introduce error into the results. The role of each such error in affecting the outcome of the EUAC must be known to a decision-maker if informed decisions are to be made with confidence. The issues associated with a deterministic EUAC model, like sensitivity to discount rate or volatility of underlying commodity prices, could be addressed by developing a stochastic life-cycle cost model (LCCA). Such an approach allows input variables to range across their more recent historic variations utilizing a Monte Carlo Simulation (MCS) (*14*).

INITIAL AND MAINTENACE COST ESTIMATIONS

Although there have been previous attempts to use historical gravel road maintenance cost analysis for low-volume roads in Minnesota, historical cost analysis in Minnesota reveals inaccuracies in data recorded by field crews, with data in many cases not recorded in proper categories (*5*). "Maintenance activities for bituminous roads were sometimes charged to gravel roads and vice versa" (*5*). Therefore, a methodology that estimates the cost of surfacing and maintaining gravel roads was adopted, and this has proved useful when requirements for labor, equipment and materials cannot be accurately predicted based on historical analysis (*5*). Available bid records were also used to estimate costs of double Otta seal implementations (Table 1).

TABLE 1 Costs for Double Otta Seal Projects Over the Past Two Years in Winona County, MN

Project location	**Year**	**Double Otta seal cots (USD/mile)**
CSAH 2, Winona county, MN	2016	57,000
CSAH 13, Winona county, MN	2016	67,600
CRs 31, 37 and 116, Winona county, MN	2017	59,800

Stochastic LCCA

Goodness-of-fit tests using Komogorov–Smirnov (K–S), Anderson–Darling (A–D) and Chi-squared tests were done to determine a good fit distribution for total rehabilitation and mainline roadway costs, and the final good fit distributions were then used to perform a MCS for a probabilistic LCCA to demonstrate the value of using the proposed approach. The probability distributions were directly incorporated into spreadsheet using @risk software. A MCS uses the defined distribution to cover all possible outcomes to calculate the LCC for each scenario and associate the calculated LCC with an estimated probability.

To conduct the stochastic LCCA, a MCS based model was developed, and each simulation, with times ranging from 20 s to 55 s, was iterated 100,000 times. Figure 1 shows the EUAC results for both double Otta seal and gravel roads throughout their life cycles. As shown in the figure, upgrading a one-mile gravel road to double Otta seal would require an average of 2,400 USD in annual expenditures. Figure 1 also indicates that, in nearly 20% of various possible scenarios, surfacing a road with double Otta seal might incur the same costs as those for gravel roads.

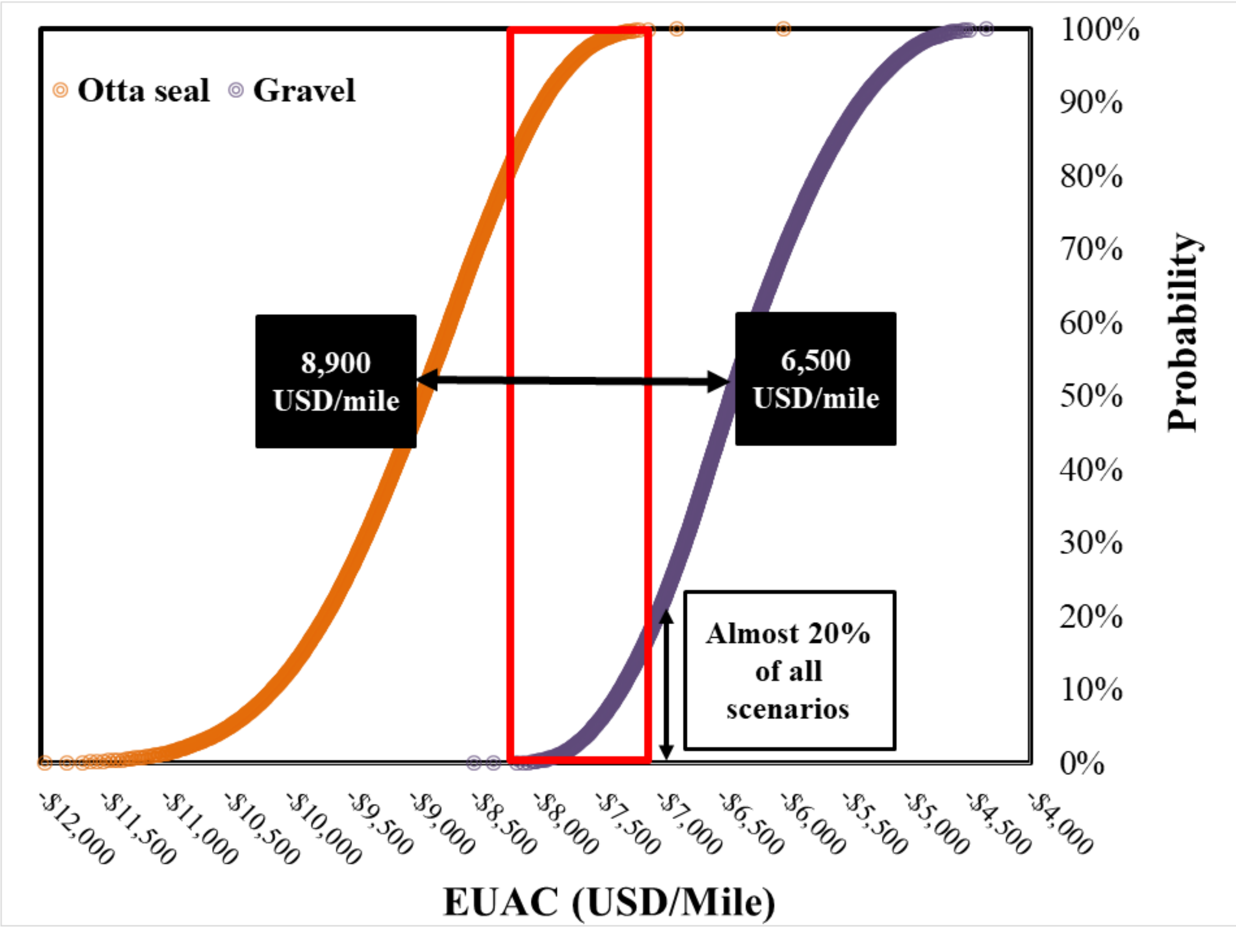

FIGURE 1 Stochastic LCCA results; double Otta seal versus gravel road.

Traffic volume based economic analysis

To study the impact of traffic on annual maintenance cost of gravel roads, a detailed questionnaire was developed for this purpose and sent to some Minnesota county engineering offices and some Iowa counties who had experienced similar climatic and traffic conditions. This survey included detailed questions about items such as gravel road service life and graveling and grading frequency under different traffic conditions.

As in the previous section, an economic analysis was employed to compare the annual maintenance costs of maintaining gravel roads under different traffic volume and track traffic scenarios. Unlike what was observed in previous section, the degree of uncertainty associated with grading frequency and gravel roads service life are not significant, and discrete values can be used to describe these two factors. Determinate life cycle cost analysis was then used to assist in making decisions as to whether or not to upgrade a gravel road to one with an Otta seal surface.

A maximum Otta seal annual maintenance cost value of 120,000 USD (see Figure 2) was taken as the economic criterion. Figure 2 indicates that gravel roads with high truck traffic and ADT more than 200 are good gravel road candidates for upgrading to Otta seal roads. The approximate percentages of miles of gravel for both categories (economic and non-economic) are shown in Figure 2, where it can be seen that there are few miles of gravel road in the high traffic volume category. In addition, since all the low-truck-traffic gravel roads are in the non-economic category, for those gravel roads it may not be possible to justify Otta seal surfacing based solely on economic analysis.

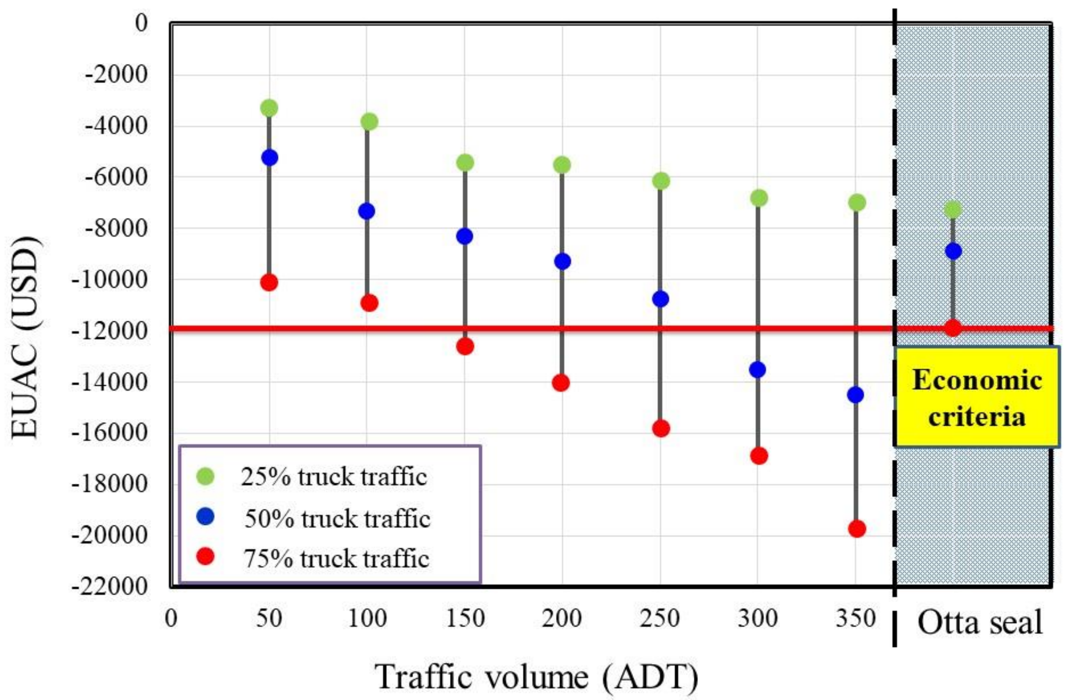

FIGURE 2 Results of traffic volume based economic analysis.

CONCLUSIONS

Stochastic economic analyses was conducted to determine the investment needed to upgrade gravel road to an Otta seal road. Since historical bid and performance records of Otta seal in Iowa were not available, Minnesota was used as a case study for conducting the analysis. Although the results of the economic analysis reveal that in some cases an upgrade to Otta seal might be justified by maintenance savings alone, the analysis showed that maintenance savings alone in most cases do not provide good justification for the investment. Another economic analysis was conducted to determine the best times for upgrading roads to surfaces covered with BST, taking traffic volume into consideration for four counties in Minnesota and Iowa, with results revealing that, for 15% of gravel roads, it might be possible to justify Otta seal surfacing based solely on economic analysis.

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