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Optimizing Road Preservation

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Problem Statement:

Roads and streets deteriorate via known mechanisms but at highly variable rates. Further, treatment methods for road repair and rehabilitation are known to extend the life of road surfaces but for highly variable lengths of time. Each particular state of road deterioration has differing treatments. The objective of minimizing life cycle costs within an acceptable level of road quality has proven difficult to optimize given this discrete-stochastic reality.

The condition state of any given road section can be objectively assessed from external observation and non-destructive testing. Thus, over time the rate of deterioration of a road section can be tracked and reliably projected for limited time periods. Treatment costs can be reliably assessed and projected for limited time periods.

It is important to clarify what is meant by a *section* of road. This refers to any given section of road that is exhibiting significantly similar deterioration performance. This almost always corresponds to a length of road with the same design, loading, and environmental conditions. If any of these three factors varies, it is highly probable that the long term performance will be similar. The exception is where the design is common but actual construction did not consistently match the specified design. A little clarification on environmental conditions can be most easily explained in terms of moisture conditions. The strength of soil, sand, and gravel structures is highly variant depending on moisture conditions. Sub-surface moisture conditions can vary significantly due to groundwater effects without being apparent from surface observation. Thus a road may be consistently constructed according to a specified design and experience similar truck loading yet have specific sections that deteriorate significantly more rapidly due to excess sub-surface moisture. Where this occurs the performance over time becomes inconsistent and the road length requires sectioning from its heterogeneous deterioration into sections of homogeneous deterioration.

Any specific section of road will deteriorate in a typical way given its specific design, truck loading, and environmental conditions. However, although deterioration can be observed to differ from section to section of road, this fact is not as daunting as it first appears. This is because there are only a limited number of proven and efficient road treatments, and each specific treatment is appropriate for only a specific state of deterioration. Crack filling treatment is, as the name suggests, for filling cracks once they reach a sufficient width and frequency that crack filling is cost-effective. A crack filling treatment would be senseless as a response to road lane rutting. The challenge in observing and recording road section deterioration then becomes the challenge of reliably grouping the road deterioration into useful condition states that represent appropriate conditions for the application of a specific treatment.

One simple way to observe and record condition state is to identify specific mechanisms of road condition deterioration and then observe their condition and extent. To use the road cracking again, imagine that cracks are only effectively treated when they exceed a particular minimum width, and only economical to treat when the extent of cracking reaches a particular total length of cracking per kilometer. Cracking can thus be recorded in terms of the number of meters of cracking/kilometer for cracking that exceeds the minimum treatable width.

Thus, for a reasonable set of possible treatments (typically less than 10), relevant deterioration conditions are identified and recorded annually or semi-annually in terms of severity and extent. Then for each treatment, a specific severity and extent condition state is established that experience shows is the most effective condition at which to apply that specific treatment.

Optimization has been defined as minimizing life cycle costs. Typically this optimization is based on net present value analysis but simple total long run summation can be used as well.

One of the most important concepts in optimizing road life cycle costs is preventative maintenance. It has long been observed that doing a low cost repair can delay or forestall the need for a more expensive treatment. Crack filling is an easily understood example. If cracks are not filled, water infiltrates and weakens the structure thus leading to patches of sever failure requiring deep patching. Fastidious crack filling is one of the most important aspects of preventative maintenance due to its comparatively low costs in relation to the cost of deep patching due to water infiltration. In simple terms the optimization of road life cycle costs can be thought of as optimal timing of preventative maintenance and postponement of more expensive treatments. Typically, a road section will require rebuilding at some point, however, the time it takes for a road to reach the condition state requiring rebuilding can be delayed a very long time; certainly 5 to 10 year postponement is possible with sophisticated maintenance. This can mean a substantial reduction in life cycle costs easily exceeding 25%.

Optimizing can be seen to involve projecting from the current state to probable future states when a preventative treatment will effectively treat the road structure such that it can withstand continued truck loading without more expensive repair. Deterministic projection has proven impractical, if not impossible, given the complexity of soil, gravel, and pavement load bearing performance. However, judgment of experienced employees can be used to create probability tables projecting performance into the future. Bayesian statistical methods have proven effective in codifying employee experience.

Problem Objective:

Develop a methodology for solving the optimization problem of minimizing life cycle costs subject to the constraints:

- acceptable road quality,
- treatments available,
- preventative maintenance, and
- budget limitations.