Maintenance and Rehabilitation

Advanced management strategies for road asset management

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Abstract

Frequent further developments in management methods require detailed information about lifetime, life cycle considerations and financial ratios of road assets. Economic indicators are supplied by a future-orientated asset management making the sustainability of the maintenance efforts measurable. The road maintenance has to ensure not only an economic use of resources, but also the maximum benefit for the road users and the long-term preservation of the financial value of the road assets. The permanent availability at a safe level is a key performance indicator for road networks and a measure of the quality of these networks. Variational calculations can show the road condition development depending on the invested financial funds. With the help of these scenarios it is easy to detect if the asset values will be preserved in the future or there will be a loss in the assets. Detailed life cycle considerations are used for the analysis of different maintenance strategies. With a break down maintenance strategy the status and comfort level is at its lowest, because only already incurred damage will be locally repaired. With a preventive maintenance strategy in the sense of a prevention or minimization of damage and restrictions in the availability maintenance measures are carried out in timely fixed intervals. Final aim of a predictive maintenance strategy is the continuous, uninterrupted availability of the road network. With this strategy, maintenance works with a fixed and reliable lifetime have to be carried out at the optimum time. The choice of the maintenance strategy has a direct influence on the financial needs for the maintenance of roads and the availability of the network to its users. Therefore, advanced management strategies for road asset management are vital to preserve the asset values and assure safe and reliable road networks for passenger and freight transport at all times.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

INTRODUCTION

“Road asset management looks at optimizing the level and the allocation of road maintenance funding in relation to medium- and long-term results of road conditions and road user costs.” [1] This is a both simple and meaningful definition of road asset management by the Asian Development Bank summarizing the challenges every road asset manager has to face. Comparable to all other sectors in the economy where the value and condition of all assets being introduced in any economic process must be known anytime, this also applies to road agencies around the world. Thus, the value and condition of road assets are more difficult to determine than for example machinery in factories. Looking for the reasons, it becomes obvious that

- the extent of road networks within whole countries means changing conditions throughout the networks,
- pavements contain mixtures of materials such as gravel, asphalt and concrete which are not homogeneous but comprise different characteristics,
- road assets are subject to climatic influences which are undergoing major changes worldwide and
- traffic loads are increasing during the lifetime of any road asset with an unpredictable timely distribution.

A special issue for the asset manager are urban roads. In Germany, two thirds of the total national road length are urban roads (that equals about 460,000 km). The knowledge about these roads is limited: Very often, the construction history and therefore the layer structure is unknown. Net wide condition surveys can only cover the surface conditions and not the structure conditions what makes predictions about the lifetime and the deterioration difficult.

Many other specific reasons make the evaluation of any road network unique and leave the asset manager alone with setting standards for maintenance. The aim of the economical maintenance is the highest possible user availability of the road network enabling the users to travel in a convenient, safe and quick manner.

A common categorization of performance indicators [2] covers two fields, knowledge/ capability and sustainability:

Table 1 - Performance Indicators [2]

Knowledge and Capability	Sustainability
Capacity to complete benchmarking survey	Funding of Life Cycle Cost
Use of IIMM principles (according to [3])	Road & bridge asset life cycle funding gap
Adoption of road asset management plans	Road & bridge asset consumption ratio
Management of road related risks	Road & bridge asset sustainability ratio
Use of long-term financial plans	
Period of long-term financial plans	
Infrastructure effects in long-term financial plans	

For the road agency, the preservation of the asset value is also of major interest. Strategies of maintenance depend on life cycle analyses of the assets and determine the availability of the road network. Furthermore, the financial effort to preserve the network value needs careful prediction of the condition development.

1. BASIC REQUIREMENTS OF ROAD ASSET MANAGEMENT

1.1. Database Requirements

It is vital to have an up-to-date database of pavement management information for any asset management project. The necessary data can be divided into the two groups of inventory and condition data.

Geographical inventory data relies on location referencing. Most common are linear referencing systems consisting of edges and nodes. The nodes are usually part of a geographic information system with information in the form of eastings and northings which can easily be obtained from the global positioning system. The connection of the nodes are the edges, typically the linear distance between the nodes.

Road structure data as the second important inventory data gives information about the pavement layers (type, thickness, composition, date of building and probably maintenance) and the subbase. It is best to gather this data from the construction history (contracts, as-built-plans) but if there is a lack of information in the files, cores and/or trial pits can be very useful to fill any gaps.

There are different methods to collect condition data. To evaluate the pavement, visual and/or automated condition surveys have to be conducted. On arterial and trunk roads, an automated condition survey is recommended for safety reasons. On other roads, visual inspections serve the same purpose. If there is the need to collect condition data of sidewalks, parking areas and other sections which are outside roadways, a visual inspection for these is mandatory anyway. There are no reliable automated condition survey methods covering these areas. The most common condition data is collected about

- Roughness,
- Surface texture,
- Skid resistance,
- Wheel track rutting,
- Cracking and
- Surface defects.

A description of the indicators and the methods of collection of this condition data can be found in [4].

Figure 1 - Examples for poor road condition: crocodile cracks (left) and badly rehabilitated excavation (right)

In addition, it is useful to have usage and environmental data available such as the annual average daily traffic (AADT), the percentage of heavy commercial vehicles (HCV) and information about rainfall, temperature and other weather data. In the first step, most asset management programs work without usage and environmental data, but the output quality can of course be improved when using all available data to the broadest extent. However, all collected data must be held up to date what should be considered before the first collection.

1.2. Data evaluation

Almost no condition data is up-to-date on the day it is used. Data collection of a road network can require up to one year depending on the systems being used: Automated condition data systems using laser beams cannot work on wet surfaces due to multi-reflections of the beam making the results unusable. Visual inspections outside roadways cannot be conducted in snowy conditions covering part of the surfaces. After the data collection, a plausibility control is mandatory. All plausible data is then standardized and transferred into grades what is the most common way to evaluate road conditions. One possibility to rate the grades is the Pavement Condition Index (PCI) as described in [5].

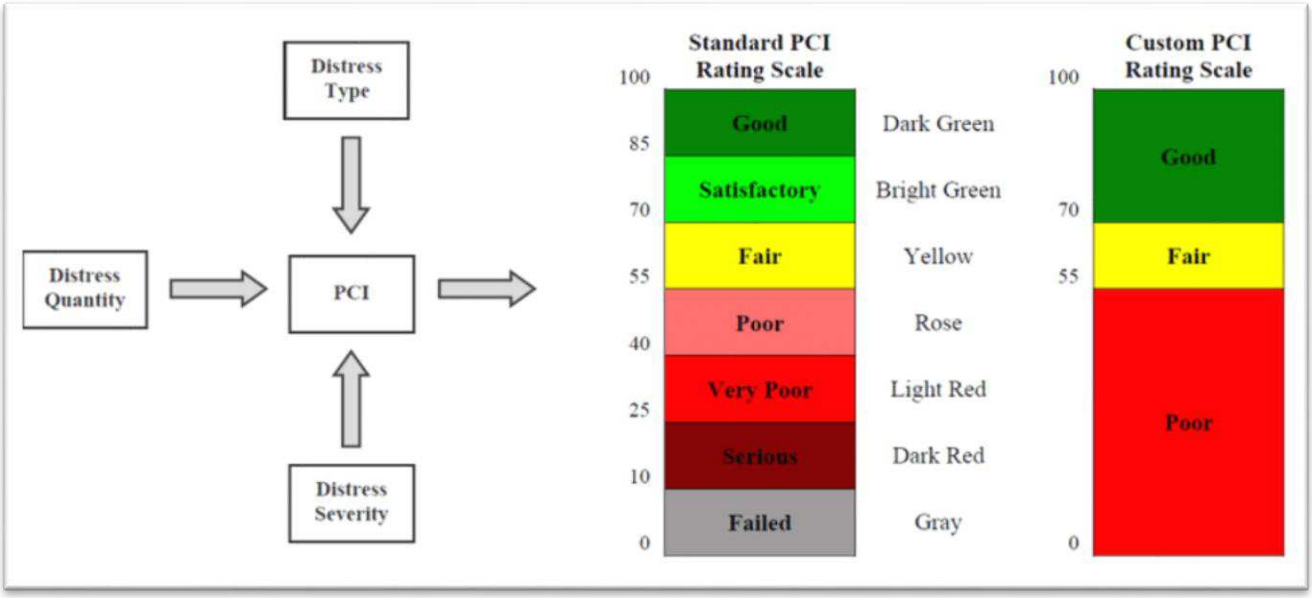


Figure 2 - Pavement Condition Index (PCI) ranges [5]

Most road agencies customize the standard PCI rating scale for mapping purposes. Maps give a quick reference to the overall condition of a network but do not allow maintenance planning on a project level. The PCI does not give sufficient information for a diagnosis of the damage and therefore for the adequate treatment or repair.

1.3. Deterioration modelling

To actualize collected condition data, the application of various deterioration models is necessary. This allows the road agency to extrapolate the data to any time point after the date of the collection.

The most important question for deterioration modelling is the question of confidence in the output. The asset manager has to be aware of the fact that the less input data is available the less reliable the output data will be. It is both possible to predict the network condition in a given timeframe and to predict the amount of money that will be sufficient to maintain the network in the recommended condition.

Two approaches for the prediction of the pavement condition can be made, either a deterministic or a probabilistic approach. Both models have advantages and disadvantages. With a deterministic model, only a single condition value, e.g. cracks, is predicted, not taking into account the stochastic nature and variability of the value.

The application of probabilistic deterioration models is based on Markov processes determining that the condition at any given point of time is independent from the condition before this point of time. The consequence is that there is no single curve for the extrapolation of a discrete condition feature but an area of probability into which the value will develop.

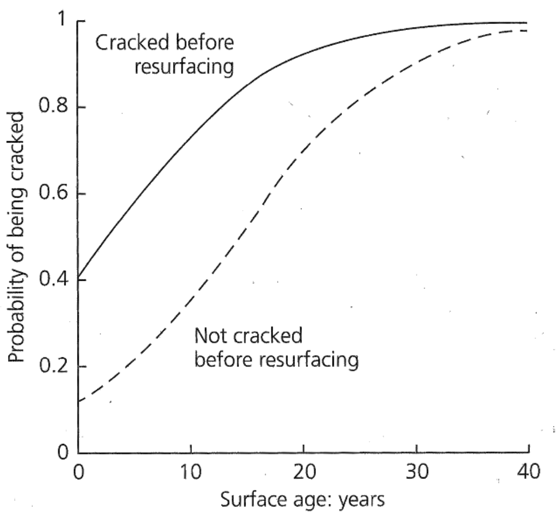


Figure 3 - Example of cracking deterioration model (probabilistic) [4]

1.4. Process description: Basic requirements

The asset manager has to assure the careful implementation of all requirements described in this chapter. The more uncertain the input data is the worse will be the extrapolation of the condition data and therefore the network condition prediction finally. Money allocation will be insufficient and the availability to the user will be at a low level.

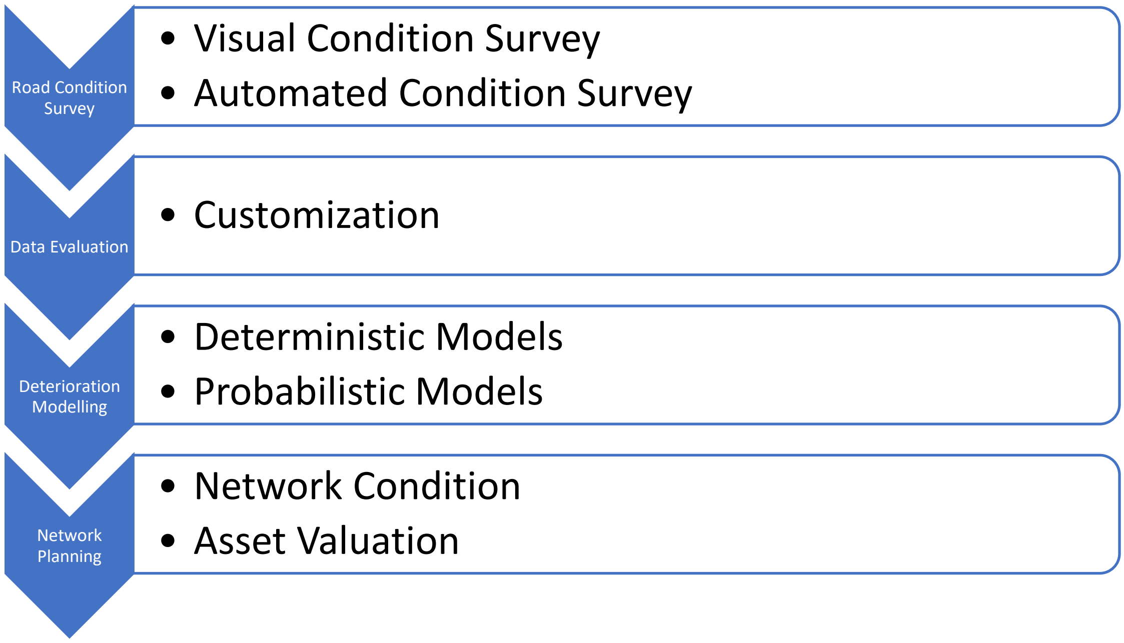


Figure 4 - Evaluation Process

2. ADVANCED ASSET MANAGEMENT STRATEGIES

2.1. Maintenance Strategies

The approach to the asset management strategies determines the network availability to the road user and the financial impact of maintenance. At first, the general aim of the management strategy has to be determined: Are the concerns of the road agency or the road users more important or are they of equal importance? The main concern of the road agency is the economical maintenance of its network; the road user is interested in an uninterrupted availability of the network at the best possible condition.

For a maintenance at the highest possible level, a predictive maintenance strategy has to be applied. The continuous, uninterrupted availability of the road network can be assured with this strategy. Maintenance works with a fixed and reliable lifetime have to be carried out at the optimum time.

The intermediate level is a preventive maintenance strategy. With a preventive maintenance strategy in the sense of the prevention or minimization of damage and restrictions in the availability maintenance measures are carried out in timely fixed intervals.

With a break down maintenance strategy the status and comfort level is at its lowest, because only already incurred damage will be locally repaired. Obstructions for road users are frequent and the overall pavement condition is poor.
Considering these three strategies, it becomes obvious that the maintenance approach has a direct influence on the pavement condition index.

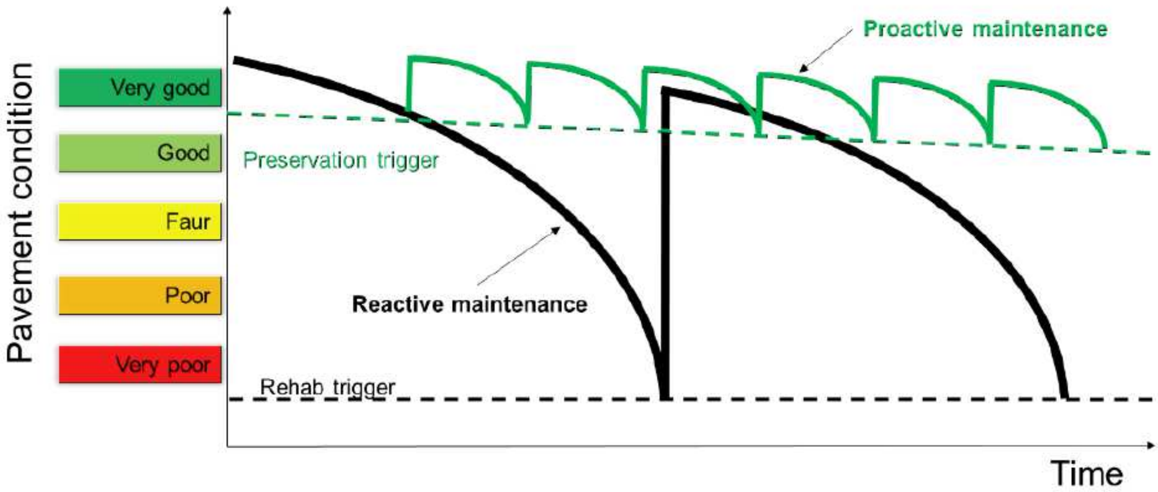


Figure 5 - Concept of proactive and reactive maintenance approach (condition-based) [6]

2.2. Life cycle considerations

The deterioration of any pavement starts right after the finish of its construction no matter whether there is traffic on it or not. Traffic will lead to a decrease of friction, ruts or cracks in wheel paths and cracks due to overload of the structure. Without traffic, climatic influences will lead to an ageing of binder components in asphalt or chippings loss on concrete pavements.

With these effects, the proper place and time to start the maintenance has to be determined. The asset manager has therefore to be aware of the life cycle of the network. During the life of a road all costs starting with the new construction and including all maintenance costs until the re-construction at the end of the life cycle have to be taken into consideration. Depending on the maintenance strategy, the life cycle costs and the ratio between benefit (availability for user and lifetime) and costs vary.

With a breakdown maintenance strategy where occurring damages will only be repaired locally, the overall costs are the highest: The lifetime of the road is the shortest as there is no action to preserve and rehabilitate the pavement layers. Maintenance costs are very high as the road has to be observed permanently to ensure safety standards for the road users. Furthermore, a lot of small local repairs have to be done demanding the maintenance crew to travel along the network permanently. This is an inefficient way to cope with maintenance repairs. The availability of the road to the users is poor. Speed limits due to insufficient road conditions will be introduced frequently; a lot of roadworks will be carried out at short notice obstructing the traffic flow.

With a preventive maintenance strategy, the lifetime of a road will be at a reasonable level. A fixed time scheme for maintenance measures (substitution of layers in asphalt pavements e. g.) minimizes damage and repairs between the timely fixed intervals. The overall costs are at an intermediate level. Availability to the road user is good as there are well-planned, announced roadworks with detours. The roadworks can be planned in adequate weather conditions and be limited to times of low traffic volume.

The longest lifetime of a road can be achieved by a predictive maintenance strategy. The asset manager has to conduct a risk analysis to predict the failure of any part of the network. With the predictive maintenance strategy, the maintenance is executed at the determined point of time when it is most cost-effective and before any asset loses performance within a defined threshold. Maintenance costs in absolute figures are high, but compared to the longest lifetime of the road, maintenance costs are reasonable.

Table 2 - costs and benefit of maintenance strategies

maintenance strategy	breakdown	preventive	predictive
maintenance costs	+	o	o
availability	-	o	+
lifetime	-	+	+
ratio costs/benefit	-	o/+	+

Legend:
+ high
o intermediate
- low

2.3. Case Study

2.3.1. Legal Requirements

Various High Courts in Germany have applied strict inspection intervals in numerous judgments where victims of road accidents have taken the road administration to court. In order to be able to identify and eliminate dangers that threaten road users due to the road condition, all administrations have an obligation to check the road network condition. The checks must be carried out at intervals that are based on the traffic significance of the street and the road condition: Roads in poor condition have to be monitored more frequently than newly built ones.
Generalizing a large variety of German High Court judgments, regular inspection trips are to be carried out at least once a week on federal highways, at least once every fortnight on federal, provincial and regional roads, and at least once a month on municipal roads. For the case study, the inspection intervals will be simplified and prolonged.
Some road authorities might feel that they are even incapable to deal with these exemplary prolonged intervals due to a shortage of financial and personnel resources. They should keep in mind that road inspection intervals depend mainly on traffic significance and road condition. Responsibility for road safety should never be an issue of financial funds.

2.3.2. Maintenance Strategy and Road Inspection

For this case study, a 1,000 m long section of a 10 m wide main road outside urban areas with an AADT of 10,000 vehicles and a HCV rate of 10 percent is considered. The asphalt road is constructed for a life cycle of 30 years.
The breakdown maintenance strategy assumes that this street is regularly inspected by a team of two skilled workers. These have a vehicle available and require two hours for an inspection including preparation and documentation of the results. The calculation base is an hourly rate of $ 45 for the skilled worker and $ 80 for the vehicle. The following intervals are used:

Table 3 – inspection intervals for breakdown maintenance strategy

Year	Inspection Interval	Annual Costs
1-5	Fortnightly	$ 8,840
6-10	Weekly	$ 17,680
11-15	Twice Weekly	$ 35,360
16-30	Three Times Weekly	$ 53,040

The shortening of the inspection intervals after the years 5, 10 and 15 is due to the deteriorating condition of the road and serves to ensure road safety.

For the preventive maintenance strategy, the necessary control intervals are as follows:

Table 4 – inspection intervals for preventive maintenance strategy

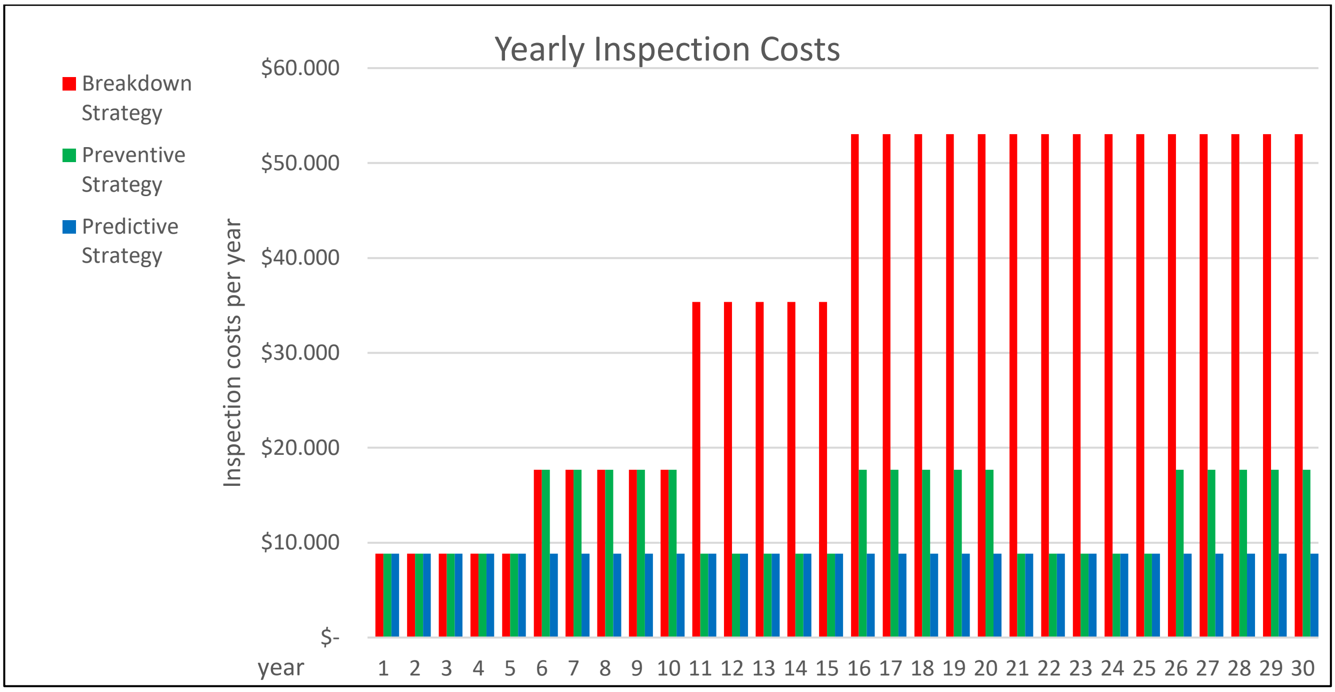
Year	Inspection Interval	Annual Costs
1-5	Fortnightly	$ 8,840
6-10	Weekly	$ 17,680
11-15	Fortnightly	$ 8,840
16-30	Weekly	$ 17,680

Again, after 5 and 15 years, it is necessary to shorten the inspection intervals. After 10 years, however, a maintenance measure is carried out, so that the road condition corresponds approximately to a new road and therefore the inspection interval can be extended again.

2.3.3. Maintenance Strategy and Roadworks

With the predictive maintenance strategy, maintenance measures are carried out frequently during the life cycle of the road so that the costs of the inspections remain constant throughout the whole life cycle. The maintenance measures ensure that safe road conditions exist at all times.

Figure 6 – yearly inspection costs for all maintenance strategies



For road maintenance, the three different strategies require different measures. There are no planned maintenance measures with the breakdown maintenance strategy. Only road damage hazardous to traffic is repaired by minor works or patchwork. It is assumed that no repairs are required in the first five years of the life cycle. From the year 6 on, necessary repairs are carried out by the street inspectors. The time required by the inspection team will increase over the years as the number of repairs increases. For this purpose, additional 2 hours will be required in the years 11-15. For the intervals 16-20 years, 21-25 years and 26-30 years, another 2 hours each are added on their time budget. In addition, material costs as a percentage of inspection costs are added: In year 6, a surcharge of 2% is added to these inspection costs, increasing by 2% per annum to a total of 50% per annum in year 30. There is no renewal of the road after 30 years. The further use is questionable.

In addition to the regular controls and the patchwork performed by the inspectors, the preventive maintenance strategy includes major maintenance measures as follows:

Table 5 – maintenance measures for preventive maintenance strategy

Year	Maintenance Measure	Costs
10	Surface layer replacement	$ 150,000
20	Surface and binder layer replacement	$ 300,000
30	Total replacement of all asphalt layers	$ 1,200,000

The calculation of the patchwork works' costs is the same as with the breakdown management strategy. After the maintenance measures, again only fortnightly checks have to be carried out for five years, because the road conditions are close to those of a new road. After 30 years, a complete renewal of the road is planned.

In the predictive maintenance strategy, maintenance works are carried out before the road deteriorates. Thus, a road control only every 14 days is required over the entire life cycle. The control team does not have to make any repairs. Major maintenance measures are calculated as follows:

Table 6 – maintenance measures for predictive maintenance strategy

Year	Maintenance Measure	Costs
8	Surface Treatment	$ 50,000
12	Surface layer replacement	$ 150,000
20	Surface and binder layer replacement	$ 300,000
25	Surface Treatment	$ 50,000
30	Total replacement of all asphalt layers	$ 1,200,000

2.3.4. Maintenance Strategy and Total Costs

The total cost overview shows that the preventive and predictive maintenance strategies cause approximately the same total costs. However, the user costs, which are lower for the predictive maintenance strategy, are not taken into account. Although users often have to accept short road-related traffic restrictions, they have the best trafficability over the entire life cycle with this strategy.

The most expensive strategy is the breakdown maintenance strategy, which also has the highest user costs, as users often experience site-related restrictions due to permanent repairs and trafficability is the worst.

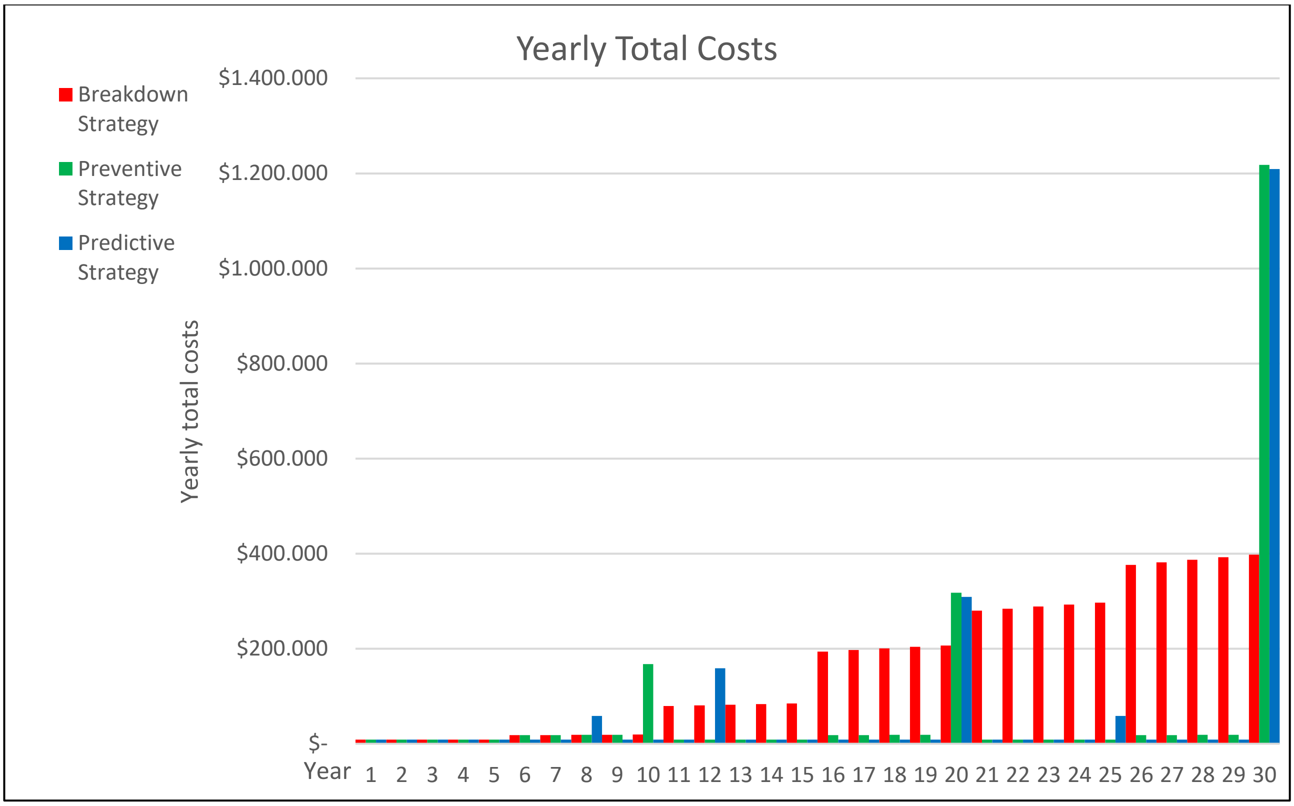


Figure 7 – yearly total costs for all maintenance strategies

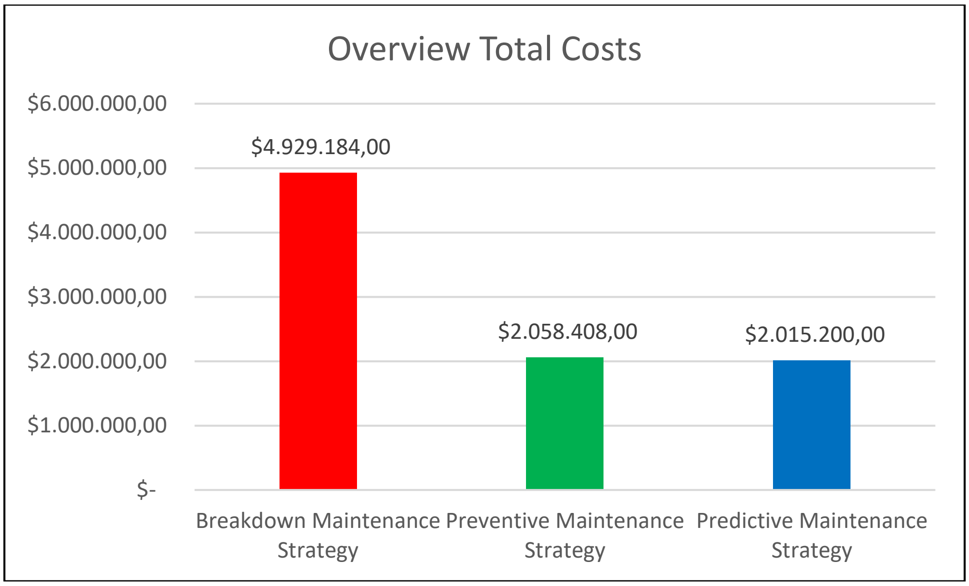


Figure 8 – overview of total costs for all maintenance strategies

For the overall evaluation and comparison of maintenance strategies, the following indicators should be taken into account by the road agencies. These indicators should be calculated over the life cycle of the road.

- Inspection costs
- Maintenance costs
- Renewal costs
- User availability (lane restrictions)
- Road safety (accident rate)

2.4. Overall economic view

The choice of the maintenance strategy is determined by the money being available for the asset management. Very often, the lack of money leads to strategies which only maintain the minimum safety standard of the roads and neglects the long-time effects of the loss of substance. Loss of substance means a loss of asset value which has to be restored by investment in road renewal. For an economical asset management it would be more efficient to invest money in a preventive maintenance strategy to hold the level of asset value. So one of the most important key performance indicators is the preservation of the asset value.

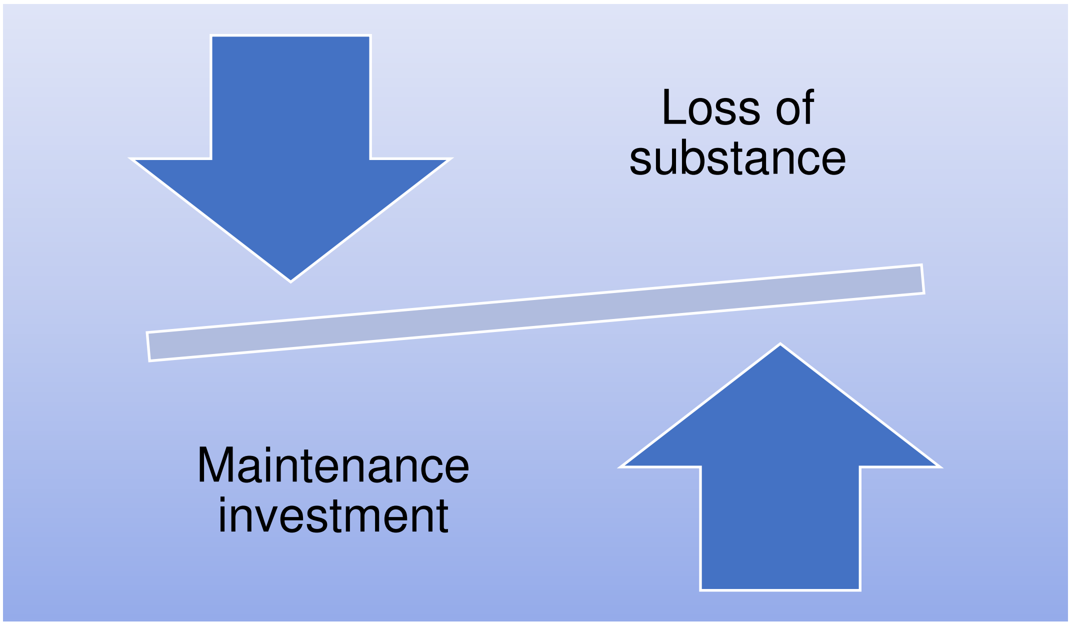


Figure 9 - Balance of losses and investments

To preserve the asset value, the sum of substance losses and of the investments through maintenance and renewals must be in balance. To verify this, the frequent condition survey of the road network is essential. Worsening network condition is one of the first indicators of a loss of substance and asset value.

The road users' costs are another key performance indicator which shows the network condition and its development. Starting with the calculation of the users' costs for an ideal network, these costs increase with a decreasing network quality as travel time increases and the accident rates grow. Mostly, the average travel time in the network is used as a key performance indicator.

Special attention has to be brought to roadworks: Traffic jams, slow speed and lane obstructions also lead to increasing costs for travel time, fuel and accidents on the user side. The more often roads have to be maintained, the higher the user costs are in the network. This depends of course on the chosen maintenance strategy (see Table 2). The availability of the network can be measured by introducing a roadworks indicator, either by the number of roadworks per kilometer, the lane restriction length within the network or the total length of detours in the network.

3. ASSET MANAGEMENT STRATEGIES IN THE FUTURE

The preservation of the asset values of road networks is not only a task for asset managers, but an issue of national economy. Roads are usually the largest asset value of a nation (for cities it is the second largest after the sewers) in a state-wide outstretch what makes a thorough management difficult. Guidelines and a reasonable budget for maintenance must be provided by the national and local governments.

There are also economic issues which demand the combination of all assets into one management system. Bridges, tunnels, sewers and pavements are vital in a high performance road network in any country. All managing agencies must work together to ensure convenient and safe rides in the road network.

A lot of issues in asset management and especially in pavement engineering are uncertain by now. Future developments should enable the asset managers to take the substance into consideration without boring or digging holes throughout their network. This will only be a reduction but no elimination of uncertainty in pavement management. With the responsible and economical use of money allocated for road maintenance and rehabilitation, asset management will contribute to prosperity and economic growth.

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