EXPERIENCED DURABILITY OF MAINTENANCE TREATMENTS

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ABSTRACT
The durability of a maintenance treatment depends on the conditions when the treatment was applied, such as road condition, traffic and environmental factors. For example, surface treatment carried out on a road with structural defects will have a shorter durability. Durability also differs between different countries due to differences in maintenance standards and strategies.

The experienced durability is based on facts but has the disadvantage that considered treatments are based on older technology. In the same time, typically, it is not known if the pavement condition was similar when the treatments were applied, and there are usually changes in traffic over time.

In Sweden, all pavement treatments longer than 100 m are required to be reported. In analysis of experienced durability app. 300 000 projects have been analyzed. The reported pavement treatment database covers a long period and contains historical information (several treatments at the same section).

The durability of treatments is calculated as the age of a treatment when a new treatment is carried out. This means that the durability is valid for treatments that were carried out back in time. Another method discussed in the paper is time-to-event studies.

This paper will show results of analyses and discuss problems in establishing expected durability.

1. INTRODUCTION
Maintenance is carried out in order to improve the condition and to prevent deterioration. A maintenance treatment will last a certain durability before new maintenance is carried out. However, time intervals or durability will vary due to changes in maintenance standards, design specifications, technical quality, maintenance strategies, budget levels, change in traffic etc. A change in the maintenance standard that results in acceptance of rougher roads will increase the durability. By time, the design specifications have been modified. Example of modifications can be changes in requirements about layer thicknesses, bitumen content, void content etc. Change in technical quality has an influence on the results. During the 90's stone mastic with a high quality stone material (porphyr) was used to a larger extent than before in Sweden. This fact in combination with tires with lighter studs has led to less wear and longer durability, especially for roads with high traffic. There can also be differences between different traffic classes depending on the chosen strategy. In times of low budget, the priority is on high-traffic roads, which will result in longer durability and poorer condition on low-traffic roads. If the budget is low one year it can be expected that less sections are maintained or that lighter maintenance is chosen, which will affect the durability.

Expected durability is used to get an estimate of the future as how many years a certain treatment will last until it reaches end of life (EOL). Expected durability can be estimated based on good knowledge about the present condition and good deterioration models.

Experienced durability shows how many years a certain treatment did last until a new treatment was carried out. The experience durability can be used to get an estimate of the expected durability.

Analysis of experienced durability by looking backward from a maintenance treatment may be difficult if the coverage of reported treatments in the past is poor.

Analysis of experienced durability by looking forward from a maintenance treatment is difficult because many treatments have not yet reached their end of life (figure 1). However, methods like “time-to-event analysis” or “survival analysis” can be used to deal by statistical methods with treatments that have not yet reached their end of life.

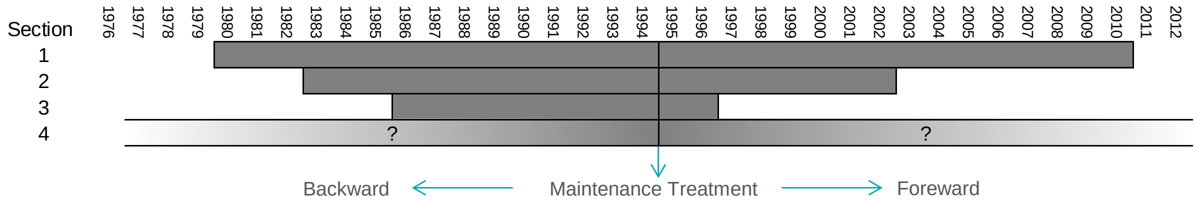


Figure 1: Backward and forward analysis of experienced durability

This paper deals with analysis of experienced durability by looking backward from a maintenance treatment. The paper will also touch the results from a Master Thesis on time-to-event analysis [Svenson, 2012]

2. AVAILABLE DATA

All data from Swedish Transport Administration Maintenance Treatment Database are used in the analysis. The database covers a very long period (1928-2005). However, during the years the quality of reported maintenance varies and when using this information in analysis, careful consideration must be taken to the quality. Figure 2 shows the distribution of total reported road length in the maintenance database 1970 – 2011. Even if the maintenance database contains information about maintenance carried out before 1980 there is a significant loss in reported maintenance before 1980. This will result in poor information about old pavements and give underestimated durability in the beginning of the analysis period. This effect decreases with time and affects roads with lower traffic more because of longer durability. If all data should be used, the result should show an increase in maintenance durability by time.

Maintenance type “Fictitious” is identified by significant changes in time series of road surface condition measurements. Maintenance type “Unknown” is identified as section without reported maintenance treatment but with surface condition measurement.

The type of maintenance carried out varies by time (Figure 3). Noticeable is the focus on “Surface Dressing on Gravel Roads” during the 80’s. This also has resulted in an increase of paved road network and a decrease of the gravel road network. Figure 4 shows the percentage of the network that is maintained as the average for each 5-year period. According to figure 4, the length of maintenance works are lower 1995-99 which corresponds well to the variation in budget.

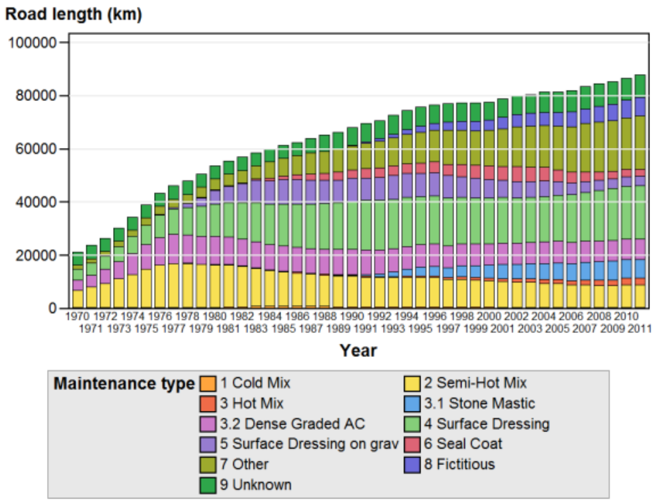


Figure 2: Reported length in the maintenance database 1970-2004

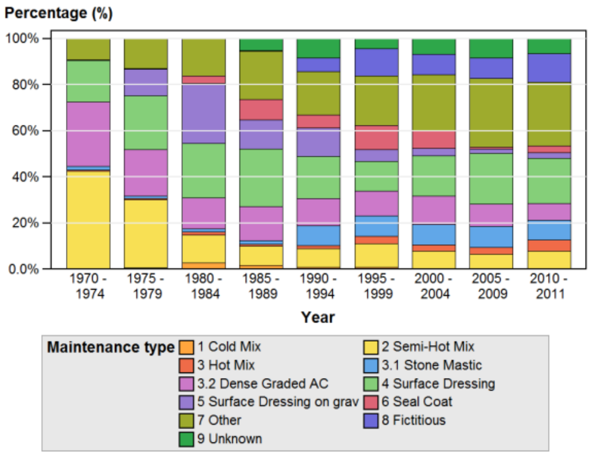


Figure 3: Distribution maintenance works per 5-year period 1970-2011

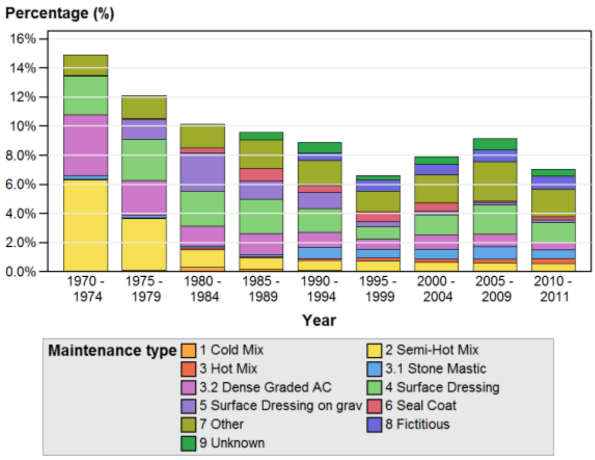


Figure 4: Percentage of maintenance works per 5-year period 1970-2011

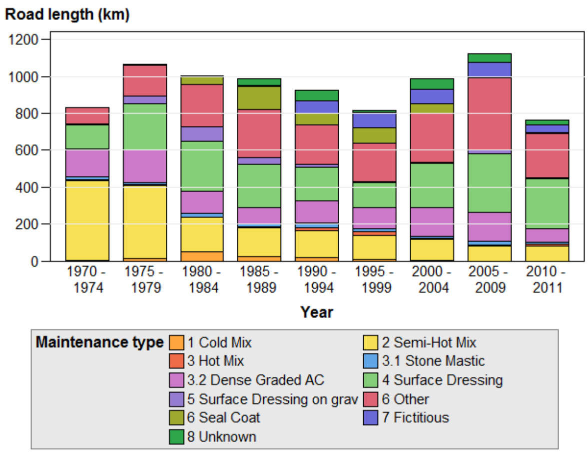


Figure 5: Distribution of maintenance in traffic class 500 -999 vehicles/day

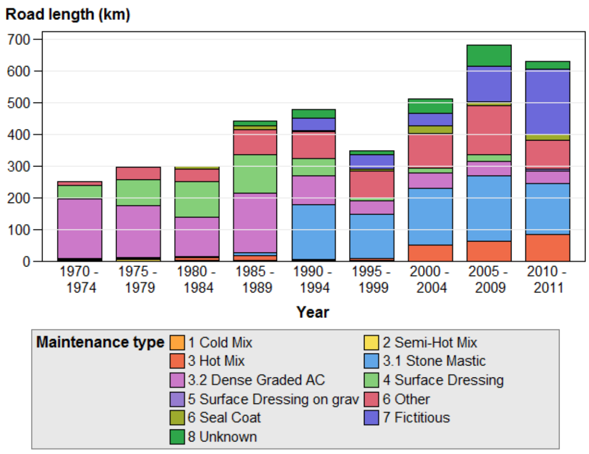


Figure 6: Distribution of maintenance in traffic class 4000-7999 vehicles per day

The example of Figure 5 and 6 shows distribution of maintenance carried out in two traffic classes. Some noteworthy is the gradual reduction of semi-hot mixes of traffic class 500-999 vehicles/day.

A total of 684450 observations are available in the database.

3. METHODOLOGY

Maintenance durability can be estimated in several ways:

1. Experienced durability of maintenance treatments is calculated as the age of a maintenance measure when new maintenance is carried out. The starting year is the year when a maintenance treatment is carried out and the ending year is when a new maintenance treatment is carried out. This means that the end year is the same but the start year varies. In the example in figure 7, the durability ends 1995 for four different homogenous sections, but the start of the durability varies. For the first three sections it has been possible to identify the starting year, but for the fourth this has not been possible because there is no information available about the starting year. The reason for this is that no maintenance is reported even if maintenance has been carried out.

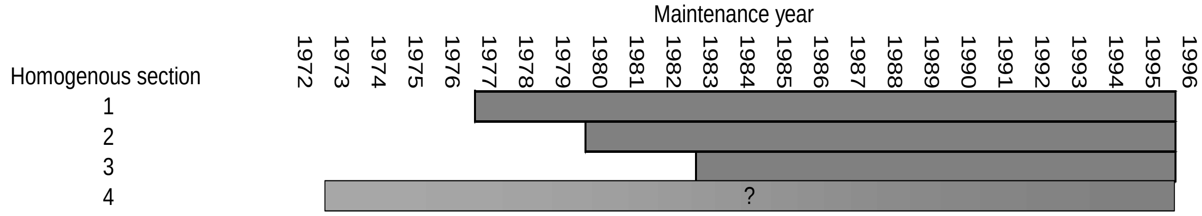


Figure 7: Example of calculation of durability based on the end year

This will result in poor information about old pavements and give too short durability in the beginning of the analysis period. This effect decreases with time and affects roads with lower traffic more because of longer durability. If all data should be used, the result should show an increase in maintenance durability by time.

One chosen method for further analysis is to use calculation of durability with a fixed ending year and limit the analysis to the last ten years (2001-2011). Even so, the results will still show an underestimation of maintenance durability. The underestimation is higher for low traffic volume roads where the durability is longer than for high traffic volume roads.

2. Maintenance durability is calculated as the time it takes until maintenance that is carried out a certain year is maintained again. The starting year of the durability is the year when a maintenance measure is carried out and the ending year is when new maintenance is carried out. This means that the start year is the same but the end year varies. In the example in figure 8, the durability starts 1985 for four different homogenous sections, but the ending year varies. For the first three sections it have been possible to identify the ending year, but for the fourth section this is not possible because the ending year has not yet occurred. By using this way to calculate durability there will be a number of sections where the ending year not yet has occurred. In statistical analysis this is called that the data are right censored. The number of censored sections increases as by time. For maintenance carried out today (2012) all sections are censored because we do not know how long the maintenance measure will last.

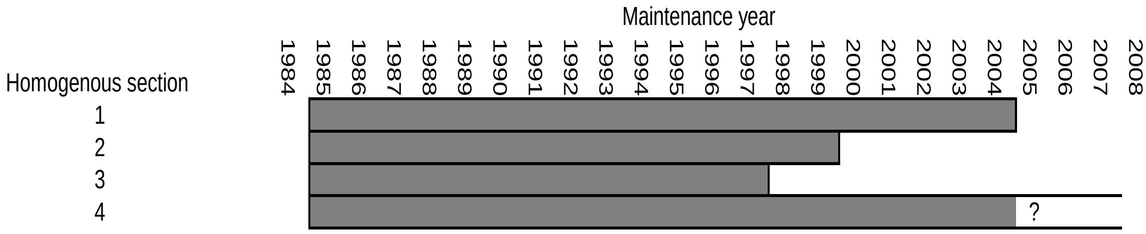


Figure 8: Calculation of durability based on start year

Using this way to calculate durability without taking censored data in account will lead to shorter durability by time, because the number of censored data is increasing by time. The fact that data are to a high degree right censored gives highly disturbed results if not the censored data are considered.

However, methods to take censored variables in account exist. Survival analysis is a branch of statistics which deals with death in biological organisms and failure in mechanical systems. This topic is called reliability theory, reliability analysis, failure rate analysis or time-to event in engineering.

Time-to-event analysis has been studied in a master thesis (Svenson).

4. ANALYSIS DATABASE

In order to analyse the durability, surface condition, change in condition and maintenance effectiveness, an analysis database was prepared. This data base is created from PMS database which in turn is created by data from surface condition measurements, maintenance data and road inventory (Figure 9).

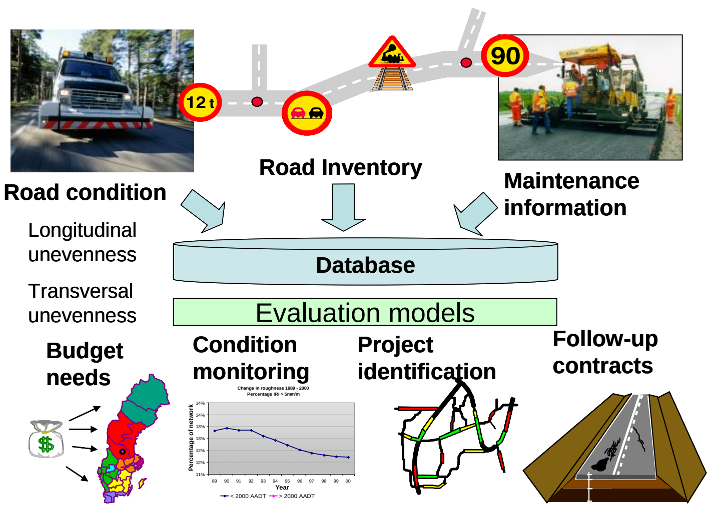


Figure 9: Overview of the Swedish Pavement Management System

The database is divided into homogeneous sections (Figure 10) where each section has the same uniform properties. A homogeneous section varies in length.

The analysis database contains about 200 000 reported treatments spread over about 360,000 homogeneous sections. A treatment can cover several homogeneous sections and a homogeneous section can have multiple treatments at different times.

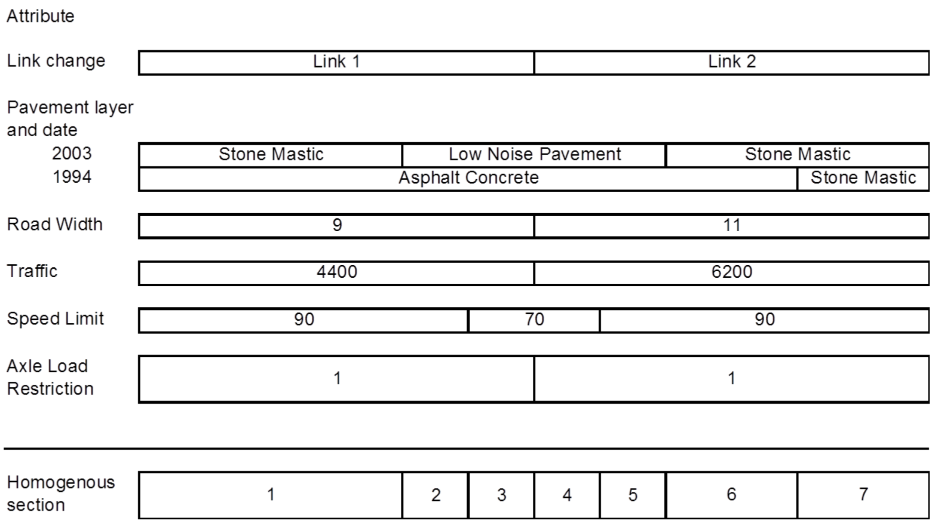


Figure 10: Segmentation in homogenous section

The data have been processed so that:

- Fictitious measures have been added where the condition shows a significant improvement between the two measurements. A fictitious treatment is then considered as a non-reported measure.
- Treatments that do not show a significant improvement between the two measurements are noted.
- Treatments that do not show a significant improvement but which is adjacent to a stretch of significant improvement are noted.
- Treatments that are close together in time - within two years - are considered as one treatment. An example can be that first year an adjustment was carried out and the following year a new surface course.

For each treatment, the condition before the measure has been analysed to assess factors that have a significant impact on decisions about the treatment. The processing is based on information of predicted condition before and after maintenance treatments. The prediction is an extrapolation, forward or backward, of a trend line of condition time series, before and after a treatment (Figure 11). Predictions for a longer time than 5 years are excluded since they are considered as uncertain.

Furthermore, the database is divided into two parts:

1. All treatments are included
2. Treatments without a significant effect are excluded

The first part is expected to give an underestimated durability since it includes sections that in many cases have been maintained before the condition is unacceptable and wrongly reported maintenance.

The second part is expected to give an overestimated durability since it excludes sections that are in poor condition of other reasons than what is measured. E.g. a reported maintained section shows no significant improvement in rut depth or roughness but all cracks have been sealed.

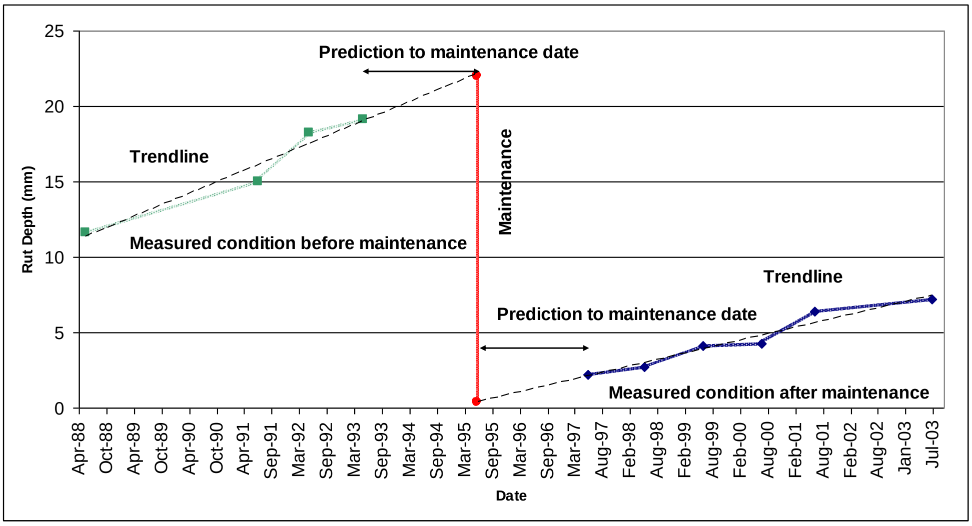


Figure 11: Example of prediction of condition at maintenance date

5. RESULTS

3.2 Experienced durability

The results are presented as line graphs, stapled bar charts and box charts. The box-charts are presented according to figure 12.

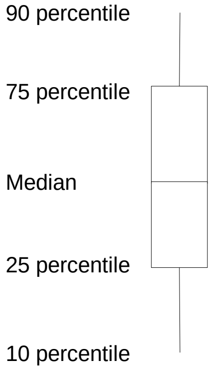
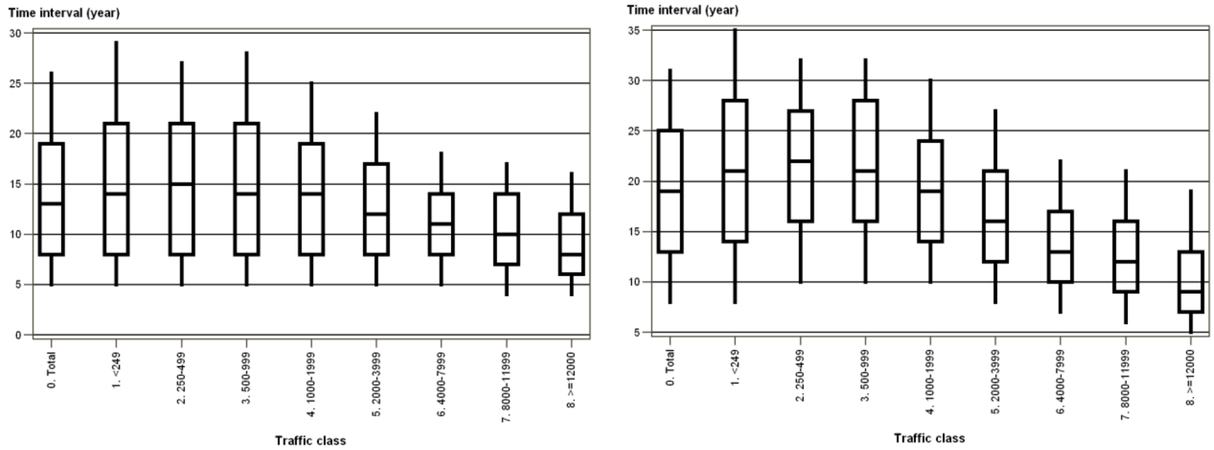


Figure 12: Boxes in diagrams

Homogenous sections with length less than 50 m are excluded and no statistics are presented for groups with a summarised length less than 10 km and a number of homogenous sections that are less than 20. All calculations of statistics are weighted with homogenous section length.

Figure 13 shows the results in different traffic classes for the period 2000-2010. The durability and deviation is higher when the traffic is lower. Analysed of data where maintenance with no effect are included shows shorter durability than data where maintenance with no effect are excluded. The figure show than a median durability of the Swedish network is app. 13 years for all treatments and app. 19 years when treatments without significant effect are excluded.



All treatments

Treatments without significant effect excluded

Figure 13: Durability of maintenance work for maintenance periods that end 2000-2010

Figure 14 shows the durability per traffic class and treatment year. When all treatments are included, the durability was almost the same throughout the period 2000-2010. As treatments without effect are excluded, the trend is that the durability increases during the period of the roads with traffic below 4000 vehicles / day. It should be noted that this increase is partly due to lack of access to old treatments on roads with lover traffic.

All treatments

Treatments without significant effect excluded

Figure 14: Change of durability for maintenance work in different traffic classes

The durability are differs depending on the type of maintenance carried out. Table 1 shows the median durability and the third quartile (Q3) per traffic class when treatments without significant effect are excluded. Median can be considered as expected durability. Q3 (third quartile) or 75th percentile corresponds to the durability is shorter in 75% of the observations. Q3 can be seen as a warning age. When this value is exceeded for a section, one should keep a watchful eye on the section even if the measured condition is acceptable.

The experience durability is of course depending on the types of maintenance treatment selected. This requires a little warning. The treatments are selected based on the conditions. If a road very uneven a treatment like surface dressing are not selected without extensive preparatory work in advance. Preparatory work is sometimes reported, sometimes not.

Table 1: Median and third quartile (Q3) of durability per traffic class and maintenance type

	Traffic															
	1. <249		2. 250-499		3. 500-999		4. 1000-1999		5. 2000-3999		6. 4000-7999		7. 8000-11999		8. >=12000	
Maintenance	Median	Q3	Median	Q3	Median	Q3	Median	Q3	Median	Q3	Median	Q3	Median	Q3	Median	Q3
Seal Coat (SC)	14	19	15	19	16	21	16	19	4	12	12	16	4	4		
Semi-hot mix (SHM)	25	31	23	29	21	28	14	21	12	25						
Cold Mix (CM)	24	30	14	21	22	24	17	24								
Hot Mix (HM)	20	33	22	29	22	29	17	23	14	19	13	16	12	17	9	13
Surface Dressing (SD)	20	24	21	26	22	28	22	25	19	24	17	21	16	17		
Totalt	21	28	22	27	21	28	19	24	16	21	13	17	12	16	9	13

3.3 Results from time-to event analysis

In time-to-event studies [Svenson, 2012], similar data as in analysis of experienced durability analysis are used, but included are also all sections that have not yet reached its end of life. A typical output from time-to-event analysis is survival curves (figure 15). The figure shows two curves. One curve (solid) is based only on age of the pavement and one curve (dashed) is based on age of the pavement but also on the condition.

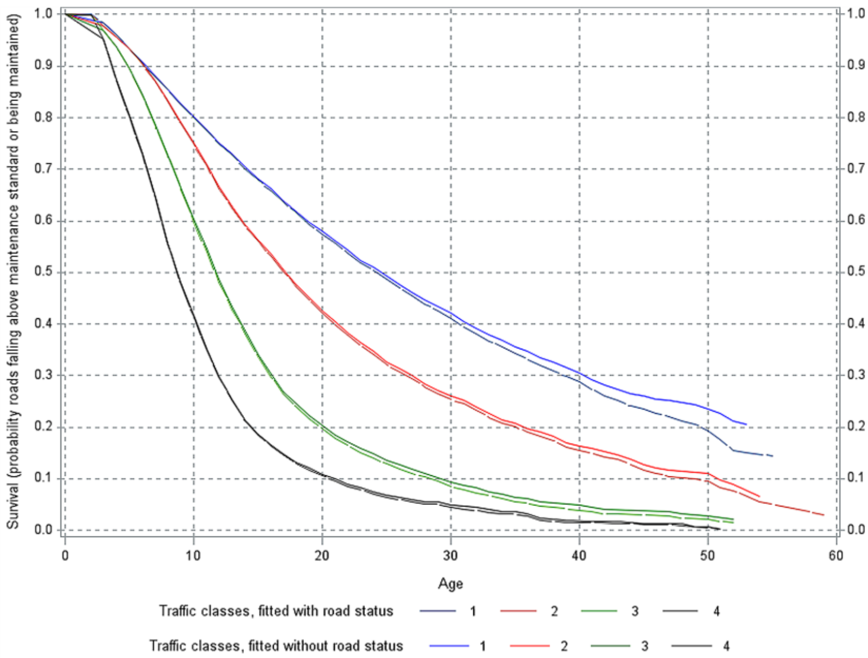


Figure 15: Model fitted survival without road condition (expected probability that a road has not been maintained – solid line) versus model fitted survival with road condition (expected probability that a road has not been maintained or has exceeded the maintenance standard – dashed line).

The median age is the age at a survival probability of 0.5. Table 2 shows a summary of median ages for different pavement types analysed by time-to- event analysis.

Table 2: Median age in different traffic classes in time-to-event analysis (years)

Pavement type	Traffic class 1 (<500*)	Traffic class 2 (500-1999*)	Traffic class 3 (2000-7999*)	Traffic class 4 (>8000*)
Stone mastic	*N/A*	*N/A*	14	11
Asphalt concrete	25	17	12	9
Seal coat	13	10	*N/A*	*N/A*
Grouted macadam	33	22	*N/A*	*N/A*
Semi-hot mix	20	14	*N/A*	*N/A*
Cold mix	15	14	8	*N/A*
Surface dressing on gravel	17	12	*N/A*	*N/A*
Hot mix	*N/A*	14	10	8
Surface dressing	23	17	11	*N/A*

* = vehicles/day

6. CONCLUSION

Analysis of experienced durability based on age information shows what has been achieved. The result shows the achieved durability of treatments carried out back in time. The results vary due to changes in time of maintenance standards, design specifications, technical quality, maintenance strategies, budget levels, change in traffic etc. The method of time-to event analysis seems like a promising method to improve the result.

To compare the durability of different treatments must be done with caution. To compare as seal coat with a hot mix is not meaningful because the choice of treatment depends on the road condition when the treatment was decided. Probably the condition before a hot mix is worse than before a seal coat.

It is important to remember that since the results are based on what has been done, the results are also dependent on the conditions under which the treatment was decided upon. This also means that the achieved durability may be different from expected durability of treatments carried out today.

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