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MASTER THESIS

Modelling the lifetime of highways

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Abstract

To maintain the quality of the Dutch road network, Rijkswaterstaat (Directorate General for Public Works and Water Management) carries out regular repairs on the roads. An important aspect of this work is being able to predict the wear of asphalt of the road. Emergency repairs can be avoided by making accurate road quality predictions and scheduling repairs according to these predictions. [...][1] In this master thesis models will be presented which describe the wear of asphalt over time. [...]

[1]The sentences which consist confidential information are denoted by [...]. For more information about these chapters, please contact Giljam Derksen (giljam.derksen@tno.nl) or Willem van Aalst (willem.vanaalst@tno.nl).

Preface

This is my Master thesis' report for the conclusion of my Master program Mathematical Sciences, at the Utrecht University. It is also the conclusion of my internship at TNO and I would like to thank all people who helped me with the project.

In first place, I thank to my two supervisors at TNO, Giljam Derksen and Arvid Halma, both research scientists. Without them I could not have make the connection between mathematics and working on a project. Especially, the statistical help and all specifications of the project from Giljam and all knowledge about Matlab and writing a Master thesis from Arvid were helpful. The combination of both supervisors with their own knowledge, feedback and way of approach was very useful.

Secondly, I also want to thank my supervisor at Utrecht University, Matin Bootsma, who always was available for me, by email and in real life. His feedback was extensive, clear and whose more mathematical approach I enjoyed.

Last but not least, I want to thank all colleagues from the department Intelligent Imaging. All doors were open the whole day and I was welcome to ask questions. They showed interest in my research and specially in the results. In particular, I want to thank Ninghang, Juan, Jasper, Gerard and Olga for the serious work performed in our room and at the same time the relaxing jokes. It was a pleasure to work with you.

I will never forget all meetings at the vending machine!

Zwijndrecht June 07, 2012

Auke Mollema

Chapter 1

Problem definition and Motivation

This first chapter explains several aspects of the lifetime of highways. After the problem is outlined we focus on how road damage evolves over the years. Is it possible to reliably predict the condition of the highway several years ahead? Before we show the data collected between 1990 and 2000, we provide more information on the kind of top layer, e.g, ZOAB, and the definition of damage.

1.1 Introduction and Motivation

To maintain the quality of the road network Rijkswaterstaat (Directorate General for Public Works and Water Management) carries out regular repairs on the roads. An important aspect of this work is to predict the wear of the asphalt of the road. The term wear in this report describes the release of stones [...] in the road (raveling).
With a good prediction of the wear, Rijkswaterstaat can:

- Avoid costly unnecessary repairs.
- Schedule maintenance on time.

The wear of the road surface is measured by plan years. The *plan year* of a hectometre section indicates the year at which a hectometre needs to be repaired. The *residual lifetime* is the expected number of years before the hectometre section needs repair. When this is accurately known,
Rijkswaterstaat can schedule maintenance on time or take alternative action. [...]

1.2 Model of the road damage

To predict the expected state of the road in five years time, one need current or historical measurements about the state of the road. This section discusses possible models for the damage change of the road. [...].

Let us first consider an example. Assume that the road is in perfect condition directly after the road is placed, so 0% damage at age 0. Suppose an inspector measured 5% damage when the road is 5 years old. We can fit several lines through the two points $(0,0)$ and $(5,5)$ (see Figure 1.1). For example, the lines $y = x$, $y = \frac{1}{5}x^2$ and $y = \sqrt{5}x$. But which one is correct? Before we will use the data and look how the roads behave, it is interesting

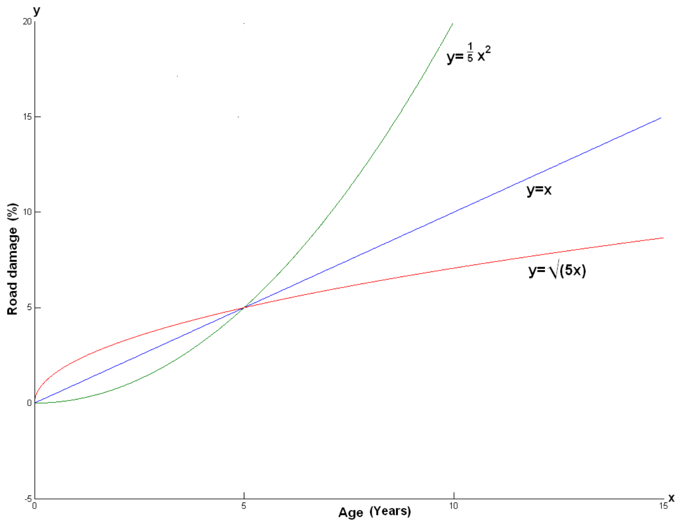

Figure 1.1: *Examples of fitting a graph through two special points*

to predict how the shape of the damage models will look like. There are some typical points, which we already knew:

- We assumed that there is no damage when the age of the road is equal to 0.
- When the damage is 100%, there is no top layer.
- Within the first few years, it is understandable that there will be none or very little damage on the roads.

What exactly is meant by 'the first few years' is not defined yet. But after these few years there are three (besides a linear model) typical possibilities of models (see Figure 1.2):

1. Starting slow and faster and faster over time (for example $y = x^2$)
2. Starting fast and slower and slower over time (for example $y = x^{\frac{1}{2}}$)
3. Starting slow and faster and faster over time, until certain mid(age)point, then it will grow slower and slower over time (for example a 'S-shape' model like $y = \frac{1}{1+e^{-x}}$)

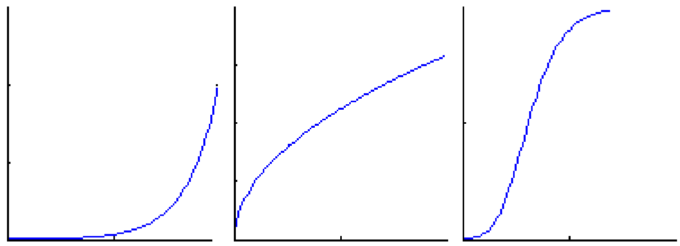

Figure 1.2: *Three typical shapes for the damage over time.*

For application of the damage model it is not necessary to know the entire graph. For example, when the damage is 100% it is already to late to avoid emergency repairs. So there is an upper bound (< 100%) for the amount of damage, which interesting to model. In particular, the first part of the graph can be described:

$$damage = c_1 t^{c_2} + c_3 \tag{1.1}$$

with t the age of the road and c_1, c_2 and c_3 are non-negative constants. If we have no damage at $t = 0$, then c_3 will be zero. If we have a linear model, we can choose $c_2 = 1$.
Conclusion: The two typical shapes of Figure 1.2 are convenient, but what factors affect the condition of the asphalt? Let us first see how asphalt is made.

1.3 ZOAB

To understand the damage on asphalt, we need to look closer at the structure. On the Dutch highways ZOAB is the most widely used kind of top layer on the asphalt. ZOAB stands for Zeer Open Asfalt Beton which is Dutch for Porous Asphalt Concrete (PAC). ZOAB consists of a mixture of crushed gravel, sand and bitumen (a syrupy binder from petroleum which has a glue function). The structure of ZOAB is very open compared with previous types of road surfaces, where the asphalt was compressed. The advantage of ZOAB is that it improves draining of rain and reduces traffic noise. However, ZOAB wears faster than other types of road surfaces. Rain,

Figure 1.3: *A cross-section of ZOAB which shows the stones, pockets and bitumen.*

sleet and icing salt cause the release of gravel. Also high humidity, temperatures around the freezing point, traffic (trucks) have a great influence on the road. [...] But the question arises whether environmental factors or ageing damages the road.

Another (negative) feature of ZOAB is groups of damage: there are big parts without stones in the top layer instead of single missing stones. [...] Since 2007, an improved variant of ZOAB is made (ZOAB+), that has a much stronger interlayer because it contains more bitumen than ZOAB. [...]

1.4 Damage

In the previous section (besides positive aspects) the negative aspects of ZOAB are mentioned. When at a certain part of the road 30 little stones are missing, it does not necessarily mean that the road has a lot of damage. This depends on where the stones are missing. If the missing stones are close together, there may be hole in the top layer while in case the missing stones are far apart, the road quality may still be fine. These 30 little parts do not need repaired, but the big part does. [...] We conclude this section

Figure 1.4: *Severe raveling of a road*

with the main question of this thesis: Can we model the lifetime of highways and can we predict the residual lifetime?

The Chapters 2 through 6, the conclusions, discussion and appendices are confidential. For more information about these chapters, please contact Giljam Derksen (giljam.derksen@tno.nl) or Willem van Aalst (willem.vanaalst@tno.nl).