NEW NORDIC PERFORMANCE MODEL FOR BETTER MAINTENANCE PLANNING

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ABSTRACT

A Nordic research project has developed a set of performance models for prediction of rutting, roughness, cracking and bearing capacity of flexible pavements at network level. Fully implemented in Pavement Management Systems it can contribute to a better platform for decision-making when the maintenance budget is allocated to specific projects.

A considerable strength of the new system of models is that it bases predictions on thorough information on pavement condition and construction. The precondition for the model system was that data should be acquired by modern traffic speed survey techniques. The reason for this being efficiency and traffic safety. The required input data; rutting, roughness, amount of cracking, centre deflection and asphalt layer thickness can all be registered by condition surveys performed at traffic speed and as such fulfil the requirements.

Among a choice of model systems, the well-known and respected HDM-4 model was selected as a basis for the new suggested Nordic model. The HDM-4 model has been calibrated to Nordic (mainly Swedish) climate, pavement materials and construction traditions using historical data sets. As a result the system of models provides predictions of the selected pavement parameters, showing good consistency with measured values.

This paper will shortly describe the model selection and calibration, and show examples of predictions. Furthermore, we will illustrate the use of the computer software, which makes implementation in existing Pavement Management Systems a fairly easy task.

The research project was financed and executed under the NordFoU umbrella, which is a pooled fund scheme for research projects seen as important to the Nordic National Road Authorities. "NordFoU Pavement Performance Models" was funded and executed by Norway, Sweden, Iceland and Denmark. Parallel to developing a model for network level, the project also looked at models for project level performance prediction.

1 BACKGROUND

The accurate prediction of pavement performance is important for efficient maintenance of road infrastructure. At network level, pavement performance prediction is essential for rational budget and resource allocation. At programming level, pavement performance prediction is needed for adequate activity planning and project prioritization, while at project level it is needed for establishing and designing the necessary corrective actions such as maintenance and rehabilitation.

To strengthen the efficiency in this area of focus, the Nordic Road Authorities in 2005 initiated a project to propose relevant performance models applicable for Nordic conditions. The project was divided in two sub-projects: Performance models for project level and network level, respectively. The project formally ended in 2011, and all reports can be found on the project website www.nordfou.org under "Projekter"\"aktuelle projekter"\"pavement models". For an introduction the reader is referred to the Summary Report (Ref./1/). The website language is Danish, but reports are in English.

This paper deals with the sub-project on pavement performance modelling for network level. The main goal of the sub-project was to develop a practical performance model for flexible road constructions based on already existing models. The project was executed through three main phases, which will be covered in this paper:

- Selection of model
- Calibration of model for Nordic conditions using historical data sets
- Development of software ready for implementation in existing PM-systems.

2 MODEL SELECTION

The specifications for the existing performance models that could be considered were:

- Ability to base predictions on both "Archive data" as construction and maintenance records, as well as traffic projection data, and "Field Recorded Data", such as bearing capacity and functional condition measurements as well as traffic count and loading data.
- Ability to use data acquired at travel speeds equal to traffic speed or create only minor disturbance of the normal traffic.
- It should be possible to calibrate the model to Nordic climate and construction traditions.

Evaluation of a wide range of existing models was carried out [ref /2/]. These models fall into four categories:

The HDM-4 software for economic evaluation of investments, which is based on the Highway Design and Maintenance Standards Model (HDM-III) developed by the World Bank. The deterioration models in HDM-4 are based on input regarding climate, traffic, and pavement data.

The MEPDG and MnPAVE Systems, both based on the comprehensive work carried out under the American SHRP project, and both heavily relying on detailed climate, traffic and pavement data in regression-based incremental-recursive modelling of pavement deterioration.

The CalME and MMOPP systems, also using incremental-recursive modelling of pavement deterioration, but using more theoretical approaches to the deterioration modelling.

Current operational Pavement Management Systems used in the Nordic countries, namely PMS Objekt used by Swedish Road Authorities, vejman.dk used by the Danish Road Directorate and the RoSy System installed in more than 100 municipalities in Denmark, Norway and Sweden.

The final choice fell on HDM-4, being a well-known tool in pavement management. The HDM-4 software has been used in many countries on a diverse range of projects and the feedback from these projects on the usability and functionality has constantly developed the software. The system is used in all parts of the world, but is especially developed to support analysis of road networks in tropic climates and in underdeveloped countries. Many of the technical models used in the software have also been extensively reviewed, undergoing both sensitivity analysis and calibration processes.

3 REPROGRAMMING IN MATLAB

In the process of adapting the HDM-4 deterioration models to Nordic conditions it was chosen to develop an independent software for predicting pavement performance. The main reasons for this approach are summarized below:

- For the possibility of freely optimize the HDM-4 deterioration models for calibration to Nordic conditions.
- For possible integration in current Nordic Pavement Performance Systems.
- For future development of pavement performance models and input parameters.

In cooperation with the Technical University of Denmark (DTU) it was chosen to use MATLAB as computational platform for the Nordic Pavement Performance Models. MATLAB (ref./3/) is suitable for both modelling and computing, but more importantly MATLAB can work with other computing languages, which makes it possible for the different Nordic Road Administrations to select their preferable computing language in future development projects.

The computing and modelling procedure performed by DTU has strictly been following the guidelines of the HDM-4 manual (Ref. /4/) as far as this manual provided adequate information.

During the modelling stage some differences between the actual output from the HDM-4 program and what would be expected from the deterioration models detailed in the HDM-4 manual were identified, which resulted in some assumptions in the computational work performed in MATLAB. Assumptions and description of the resulting MATLAB computer program can be found in (Ref./5/).

For delivering results on performance prediction, the software requires general knowledge on the road section as age, geometry and construction information, climatic zone, as well as data on traffic loading. Also the software uses condition measurements as information on the condition at the starting point of the performance prediction. As output the program delivers predicted performance of roughness (IRI), rutting, bearing capacity (Structural Number) and cracking, presented either on graphs or in spreadsheets as shown in Figure 1.

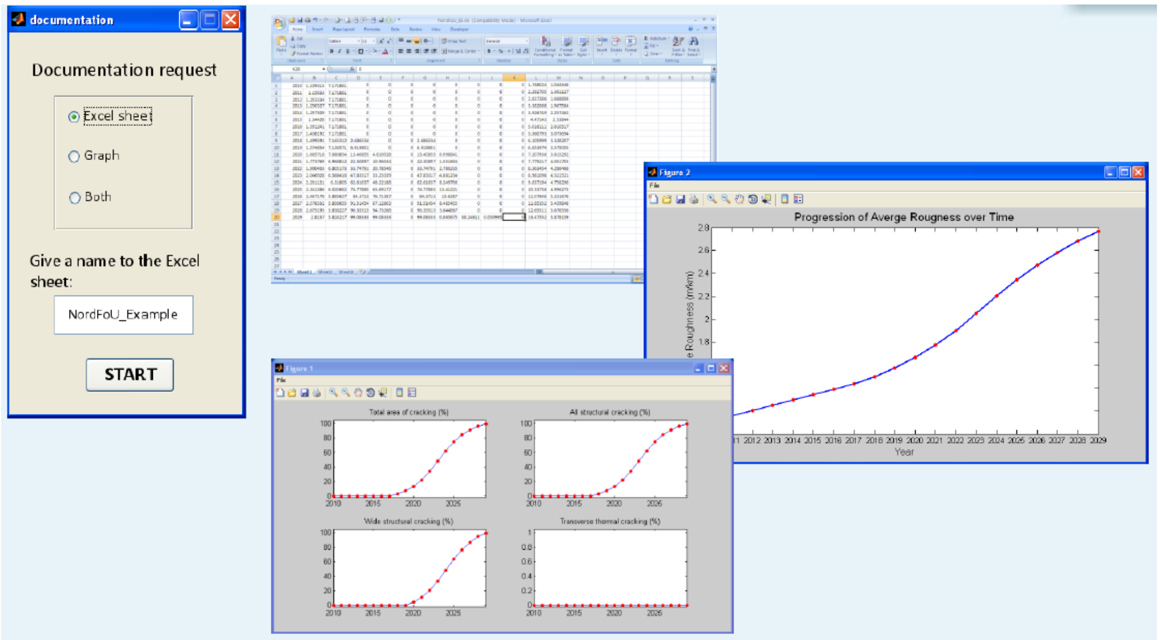

Figure 1: Output from the MATLAB program; performance prediction delivered both as graphs and in spreadsheet.

4 TEST SECTIONS

Sweden started in 1984 collecting data for the national Long Term Performance Program (LTPP). The number of test roads included in this program grew to a number of 64 at the end of the 1990'es. Each of these test roads has been monitored systematically over the years, forming an outstanding data material for establishing and calibrating deterioration models. Data from eight of these roads, all located in southern Sweden, have been used in this project for calibration of the HDM-4 deterioration models to Nordic conditions.

As part of the NordFoU project on network level analysis, it was decided to perform measurements in 2010 on the eight selected test roads. This was done partly to demonstrate the feasibility using traffic-speed monitoring equipment, but also to extend the data series with measurements performed with alternative equipment, being equipment that measures the same indicators by slightly different methods. Devices for field measurements were the Danish Traffic Speed Deflectometer (TSD) for bearing capacity measurements, and the ARAN device for rutting, roughness and crack detection measurements.

An example of measurements on test road RV31 is shown in Figures 2 and 3 below.

Figure 2: Test section RV31 northbound.

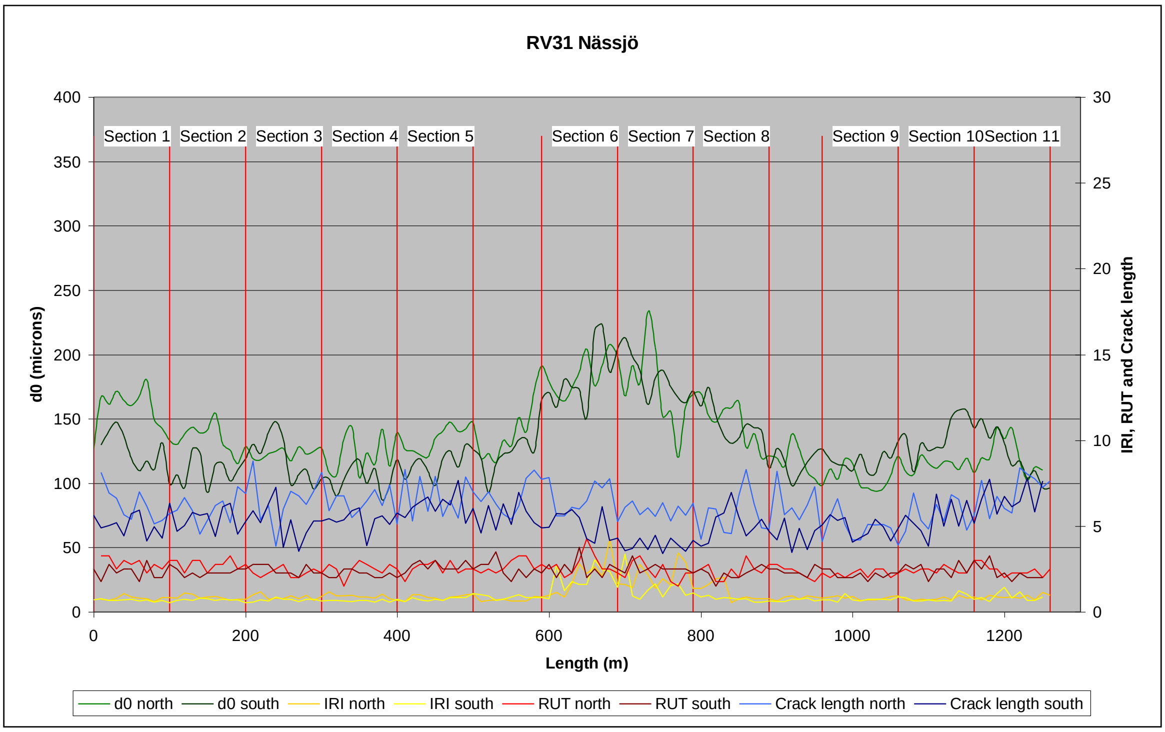

Figure 3: Condition of RV31 2010. In sub-section 6 and 7 where the road structure is weaker (higher centre deflection, d0), the pavement is also more rough.

5 CALIBRATION OF MODELS

The HDM-4 deterioration models are calibrated to Nordic conditions by fitting to the Swedish LTPP data described in the previous chapter. Before looking at field data, an extensive sensitivity analysis was conducted of both the input parameters and the calibration factors (Ref./5/). The sensitivity analysis of the input parameters identified which input parameters have significant effect on the development of roughness, and therefore should be determined with accuracy for each road section to establish the correct calibration factors.

Looking at calibration factors, it showed that some calibration factors do not have any effect on the evaluated distress types, and hence they were chosen to have the default value from HDM-4 in the following calibration process. Other calibration factors have a significant effect on one or more distress types. Roughness is the distress type affected by far the most calibration factors; hence it was decided to calibrate predicted development of cracking and rutting first, and then the predicted development of roughness.

Calibration was performed for each sub-section in the data material. Some section specific calibration factors could be calculated directly from the historical data, whereas others had to be found through an iterative process to obtain the best fit of the output from the HDM-4 deterioration models to the measured data in the LTPP databases.

The calibration of HDM-4 deterioration models resulted in section specific calibration factors (different set of calibration factors for each uniform sub-section for each specific LTPP section) and a set of standard calibration factors (weighted based on number of individual sub-sections each uniform sub-sections consists of).

An outline of methodology for the calibration process is given below:

1. Determine calibration factors directly from historical data
2. Calibrate predicted development of cracking to historical data
3. Calibrate predicted development of rutting to historical data
4. Calibrate predicted development of roughness to historical data

In the steps above the following distinction is made for the section specific calibration factors:

- Calculated section specific calibration factors, which can be calculated directly from the historical data in the Swedish LTPP databases; Step 1).
- Simulated section specific calibration factors, which require an iterative process to calibrate the output from the HDM-4 deterioration models to the historical data in the Swedish LTPP databases; Step 2) to 4).

5.1 Validation of prediction of rutting

In Figure 4 the measured data for rutting from the LTPP database can be seen against predicted development of rutting using weighted values for the section specific calibration factors in the calibrated HDM-4 deterioration models. Furthermore the root-mean-square correlation coefficient between measured and predicted values is also shown.

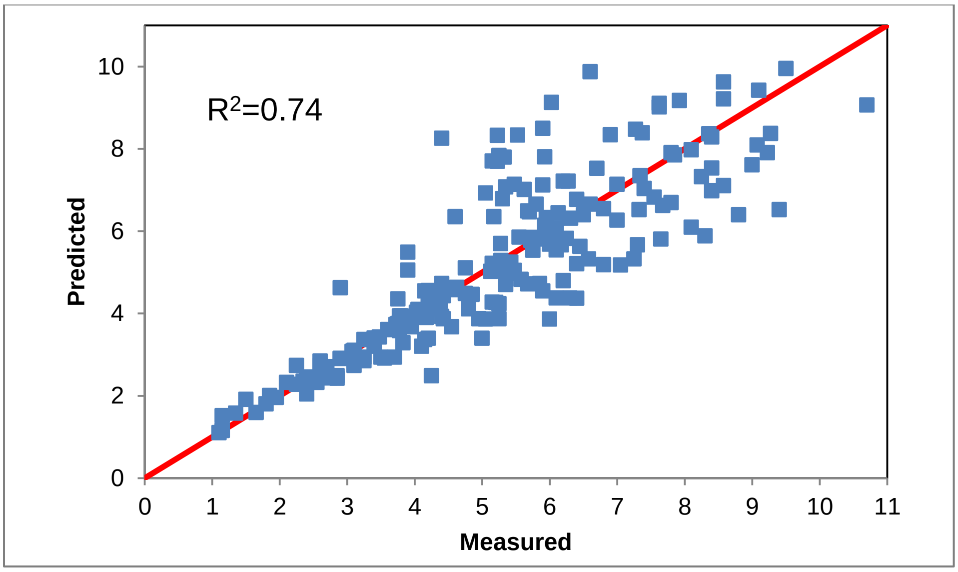

Figure 4: Correlation between measured rutting and predicted rutting for all sub-sections using weighted values for the section specific calibration factors.

It can be seen from Figure 4 that there is an acceptable to good correlation between measured and predicted rutting; especially in the first years of the prediction, when the rutting is still small. It is noted that the predicted rutting is increasingly spread out during the analysis period as a result of the increased inaccuracy of the general model compared to the section specific calibration factors.

5.2 Validation of prediction of roughness

Figure 5 shows the measured data for roughness from the LTPP database against predicted development of roughness, again using weighted calibration. Furthermore the root mean square correlation coefficient between measured and predicted values is shown.

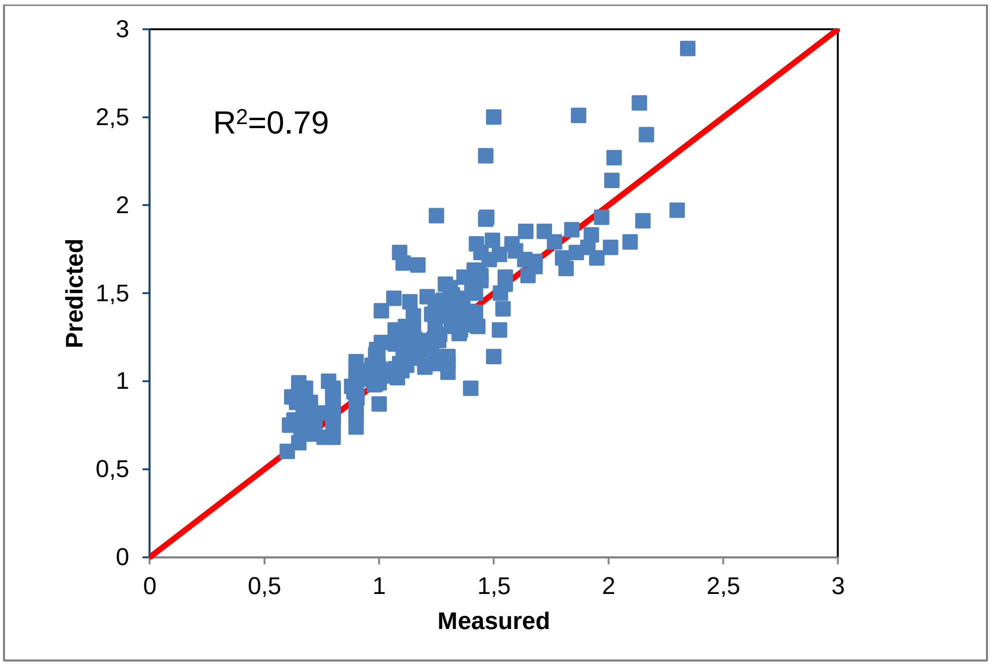

Figure 5: Correlation between measured roughness and predicted roughness for all sub-sections using weighted values for the section specific calibration factors.

The root-mean-square correlation coefficient shows an acceptable to good correlation between measured and predicted roughness; as for the prediction of rutting the error increase during the analysis period. A somewhat better correlation is obtained for roughness than for rutting; this is a result of less difference between the section specific calibration factors on sub-sections.

6 PROPOSED SYSTEM FOR DATA COLLECTION AND PERFORMANCE MODELLING

Based on the available test equipment within the Nordic countries and the framework of the calibrated HDM-4 deterioration models a harmonized system for prediction of pavement performance at network level is proposed.

The system for data collection and performance modelling may be illustrated schematically as shown in Figure 6.

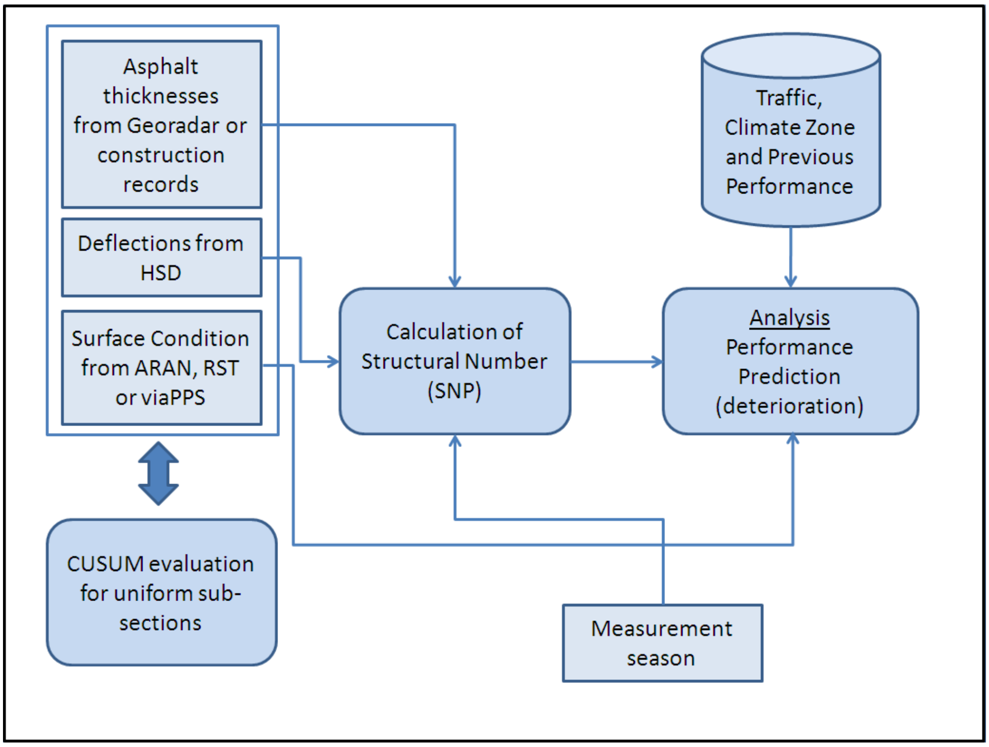

Figure 6: Overview of the new Nordic Pavement Performance System (PPS) at network level for testing and future prediction of pavement performance.

Data acquisition is proposed by using the following types of equipment, which can operate at normal traffic speed. The Nordic Road Authorities already have access to this type of devices as shown in Table 1.

Layer thicknesses can be measured with georadar or found in construction records. Only total thickness of asphalt is needed as input. Experience shows that although records are kept on maintenance and repair activities, there are often discrepancies between the bound layer thicknesses determined from the records and the reality on the road, since milling and levelling activities are seldom registered or not registered correctly.

Bearing capacity (centre deflections) can be measured with the Traffic Speed Deflectometer (TSD) or Falling Weight Deflectometer (FWD). The TSD expresses bearing capacity as Surface Curvature Index (SCI), which has demonstrated to correlate well with the development of rutting and cracking. The HDM-4 models require centre deflections, so for this project, SCI has been transformed into centre deflections.

Surface condition can be measured with ARAN, RST, viaPPS or similar traffic-speed optical and laser equipped vehicles. The condition indicators are then used as input in the HDM-4 deterioration models at the start of an analysis period or for adjustment of older simulations.

In order to determine uniform sub-sections of the road network a cumulative sum control chart (CUSUM) can be used.

Calculation of Structural Number: After determination of uniform sections the average centre deflection for each section is used as input for calculation of Structural Number in the HDM-4 deterioration models. In HDM-4 the Structural Number is a direct function of centre deflection.

Table 1: Survey Equipment in operational use in the Nordic countries.

	Traffic Speed				Equipment			
Measurement/test	***NOR***	***SWE***	***IS***	***DK***	***NOR***	***SWE***	***IS***	***DK***
Longitudinal evenness	x	X		x	ViaPPS	RST	*visual*	ARAN
Transverse evenness	x	X		x	ViaPPS	RST	*visual*	ARAN
Macro-texture	x	X	x	x	ViaPPS	RST	ROAR	ARAN
Friction	x	X	x	x	ROAR	SAAB friction	ROAR	ROAR
Bearing Capacity				x	FWD	FWD	FWD	TSD
Noise	x			x	CPX			CPX
Cracking		X		x	*visual*	RST	*visual*	ARAN
Surface defects		X		x	*visual*	RST	*visual*	ARAN
Georadar	x	X	x	x	H	H	H	H

Notes:
ViaPPS: Pavement Profile Scanner
RST: Road Surface Tester
ARAN: Automatic Road Analyzer
ROAR: Road Analyzer and Recorder
SAAB friction: Skiddometer
TSD: Traffic Speed Deflectometer
FWD: Falling Weight Deflectometer
CPX: Close Proximity
H: Not owned by road authorities, but possible to hire

7 ON-GOING WORK

The network level part of the project has been extended, planning to end in December 2012. The continuation will expand the calibration process by including data collected in the remaining geographic regions represented by the participating countries, with the aim that the deterioration models give reliable predictions for all climatic zones and road construction traditions found in the Nordic countries.

The MATLAB software was intended for use only during the calibration process, and meant as a piece of source code that could be implemented in existing pavement management systems. However, it has showed to be a quite popular program for making predictions for individual sections for special purposes. Therefore resources are also allocated for refining the MATLAB software and User’s Manual, making both more user-friendly.

8 IMPLEMENTATION

The success criterion for this work is that the suggested pavement performance models will be implemented in existing PM-Systems within the Nordic Road Administrations. But also the Nordic deterioration models may be applicable in other areas than investment and maintenance planning at network level; e.g. deterioration models could be useful to contractors and consultants. Possibly the developed MATLAB software may be applied for the following purposes:

- Functional criteria's in tender documents: Development of boundary conditions of performance criteria's to be fulfilled during a specified period after construction of road; e.g. roughness below a given value.
- Public Private Partnerships (PPP projects): Pavement Performance Models could be used to predict future pavement condition and hence future needs for re-investments in pavements.
- Structural thickness design: If a reliable calibration of models is validated for a specific region and road category, the pavement engineer/designer can check functional design criteria requirements in preliminary or detailed pavement design using the MATLAB application.
- Life Cycle Analysis: Pavement Performance Models can be used to simulate pavement performance with time for different new construction alternatives – and for subsequent maintenance actions.
- Education: Understanding of how pavement structures deteriorate and which parameters have significant effect on the development of the different distress types.

9 CONCLUSIONS

The outcome of the NordFoU pavement performance models project is computer software for predicting future conditions of flexible pavements, as well as recommendations on data collection to provide input to the Nordic Pavement Performance Models. The software is a re-programming of the HDM-4 deterioration models, calibrated for Nordic conditions.

At the end of 2012 the current MATLAB program will be improved, as the on-going work will make the performance models more robust to different climatic zones and construction traditions in Nordic countries. The program, User's Manual and other project reports will be published on the www.nordfou.org website.

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