Delft University of Technology

Use of a future maintenance demand indicator for network level asset management decision making

van Meerveld, H.; Schoenmaker, Rob; Wessels, J.F.M.; Wessels, J.

Use of a future maintenance demand indicator for network level asset management decision making.

H. van Meerveld
The Netherlands Organisation for Applied Scientific Research TNO, Delft, The Netherlands

R. Schoenmaker
Delft University of Technology, Delft, The Netherlands
J.F.M. Wessels
The Netherlands Organisation for Applied Scientific Research TNO, Delft, The Netherlands

J. Bakker
Ministry of Infrastructure and Environment, Rijkswaterstaat, Utrecht, The Netherlands

ABSTRACT: This paper discusses the development and first testing of a valid, reliable, functional and simple indicator, that represents the long term effect of short term decisions. Such an indicator can assist counteracting short term views in network level asset management decision making. Short-termism or myopia may occur in cases where service level agreements (SLA) are made upon for shorter time frames than the typical lifecycles of transport infrastructure. The developed indicator indicates the "discounted future maintenance demand" (DFMD) for a time period stretching beyond the initial agreement period (expressed in a monetary value). The main assumption here is that the effect of short term decisions are reflected in the future maintenance demand. The indicator was applied in a case using existing data and information sources. Use of the DFMD, together with other (related) indicators provides valuable insight in understanding long term effects of short term decisions.

1 INTRODUCTION

Asset management of national road and waterway networks is often performed by executive agencies of governments. The governance structure typically entails an agreement between the owner of the assets (the government) and the asset manager (the agency), called a service level agreement (SLA). In a SLA, the required performance of the network, the risks and the maintenance budget for a certain time period (e.g. several years) are agreed upon. A SLA may also include the performance indicators to be monitored during the SLA period.

The duration of the SLA may be significantly shorter than the typical lifecycle of roads, structures and waterways. This may have undesired consequences in cases where too much attention is paid to the short term performance within the SLA-period. This phenomenon of short-termism or myopia is a well-known perverse effect of performance management (Pidd, 2005; Schoenmaker & Bruijn, 2016; Smith, 1995). Short-termism may particularly prevail in times of financial scrutiny, forcing governmental bodies to maintain service levels with substantially decreased budgets. To counteract short-term views, more insight in the long-term effects of the SLA is needed. The question, however, is what indicators can be used to provide indications of the long-term effects of short term (e.g. 3-5 year) agreements.

Previous work (Wessels, Schoenmaker, Van Meerveld, Bakker, & Schavemaker, 2014) was aimed at "developing a clear, proven, consistent and simple indicator, that represents the long term effect of short term decisions". Initial research showed that there was no such indicator currently available (Ligtvoet, Bhamidipati, Herder & Verlaan, 2013). An indicator was therefore developed, which provides the "discounted future maintenance demand" (DFMD) for a time period stretching beyond the initial agreement period. The indicator is expressed in a monetary value. The idea is that the effect of short term decisions are reflected in this future maintenance demand. Furthermore, this indicator also provides means for monitoring the development of the future maintenance demand.

A proof of principle involved the application of the indicator in a Dutch case of a large transportation infrastructure asset management organisation. Although the indicator showed to be promising in making (possible) long term effects transparent, further work was required to determine the value of the indicator. Knowing the value of the indicator is necessary for the indicator to be useful in network level asset management decision making. The work therefore continued with the following aims.

1. To compile indicator data for multiple years. This would make it possible to analyse the data further, to search for patterns and trends, and to make comparisons between predictive data and data showing 'actual performance'.

2. To determine what other (financial) indicators could be relevant and to collect data for these indicators as well. This could provide contextual information that can help to analyse and explain the indicator values obtained.

3. From a practical point of view, a condition was to make use of existing data and information systems and sources, and to align the process of collecting and analysing data to current existing processes.

This paper describes the results of the research done in 2014 and 2015, and discusses the insights gained.

2 RESEARCH APPROACH

The research reported in this paper continues with the work done previously (Wessels et al., 2014). The research entailed a form of action research where research was conducted simultaneously with practical actions of investigating and supporting current practices in a case related to SLA negotiations.

The first phase of the research involved the investigation of the SLA negotiations and the related processes in the case such as forecasting, budgeting, planning, programming and executing maintenance works. Simultaneously, literature research was done to provide a framework for analysing these processes, including what indicators could be useful. The result was a list of indicators for which data should ideally be collected, and a process description on how to collect, analyse and process the data.

A second phase involved collecting data for each of the indicators identified, including the previous developed indicator for "future maintenance demand".

A third phase included a simulation. During a session with experts from the case owner organisation, the collected (historic) data were presented and discussed in a way to 're-enact' several moments in time during a fictive SLA period. This offered the opportunity to discuss what information and insights could be provided by the indicators and to determine their use for network level decision making.

The theoretic background is provided in section three and the collection of data and the simulation are provided in section four. This paper concludes with a critical review (section five) and conclusions and recommendations on further steps.

3 IDENTIFICATION AND DISCUSSION OF INDICATORS

This section discusses the various indicators that were found to be of importance. The indicators found are the result from research and practice (i.e.

they are partly based on the processes in place in case studied). Literature provides several general criteria for the quality of individual indicators (Bouckaert, 1993; Neely, Richards, Mills, Platts, & Bourne, 1997). Three generic criteria summarise these criteria (Bouckaert, 1993):

Validity: The indicator has to be measurable and has to measure what it is intended to measure;

Reliability: The indicator has to be measurable and measurements can be repeated, again and again, Availability of accurate data is an important aspect of reliability;

Functionality: The indicator has to be relevant, has to contribute to the overarching objectives. Sensitivity to change is an aspect of functionality. An indicator that stays the same over the years is not functional.

3.1 *Main indicator: the discounted future maintenance demand*

The first and main indicator of interest is referred to as the "discounted future maintenance demand", or "DFMD". The calculation of the DFMD is similar to a present value calculation. Each future maintenance demand (expressed in a monetary value) is discounted to a present value and subsequently summed up to the DFMD. Also see the equation below.

$$DFMD = \sum_{t=1}^{n} \frac{FMD_t}{(1+i)^t}$$

In the equation, *FMD* stands for future maintenance demand, *i* for the discount rate and *n* for the number of years considered for the DFMD. Reasons for discounting the value of the future maintenance demands is to is to account for the future value of money. In this application, the value for the discount was set to the default value used by the case organization in lifecycle costing analyses.

The scope of the DFMD is depending on a number of variables: (1) the time period; (2) the asset(s) or asset portfolio (e.g. pavement, structures); and (3) the type of maintenance (e.g., excluding refurbishments).

Within the case, the scope of the DFMD was set to 10 years. This period is long enough to provide a sufficient future period to prevent short-termism, but is also short enough to have data available on future maintenance demands. The period of 10 years was also considered holding the middle between an indicator being too sensitive to change and an indicator being too robust and insensitive to change. The scope was furthermore adapted to the availability of data (also see section four).

To determine the DFMD, a sufficiently reliable forecast of future maintenance is required. Figure 1

provides an example of what is represented in the DFMD. It shows the yearly expected maintenance need (expressed in a momentary values). To determine the DFMD, each value needs to be discounted (in this case, to year 0) and summed up to a total.
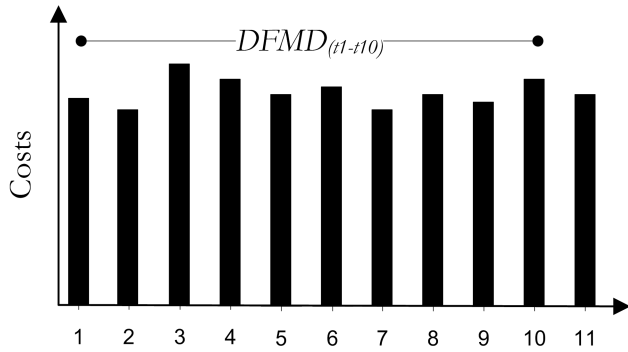
Figure 1: Example of predicted future maintenance demands (predicted at t=0).

An example is shown in Figure 2. It shows a new prediction of the future maintenance demands after one time interval. With the interval, the time period considered for the DFMD also changes (from t1-t10 to t2-t11). Changes in the predicted maintenance demand are also shown: white bar represent outflow of predicted maintenance (decreasing the DFMD) and grey bars showing the additional maintenance (increasing the DFMD) compared to figure 1.
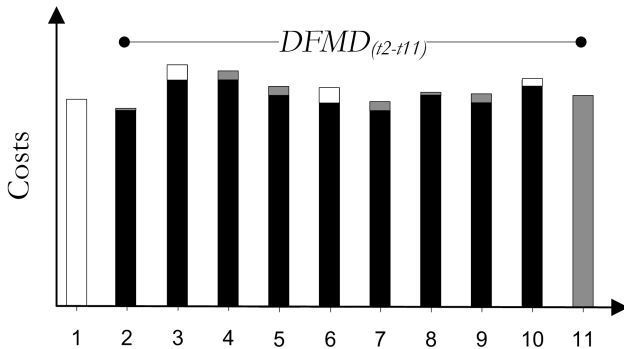
Figure 2: Example of predicted future maintenance demands (predicted at t=1)., showing changes compared to figure 1.

The DFMD can thus be seen as a vessel of (discounted) future maintenance demand with constant in- and outflow. New maintenance may be predicated (inflow) while other maintenance may be executed or no longer required (outflow). The DFMD constantly changes for two main reasons. First, the time period that is being considered changes over time. As a result, one time interval (e.g. a year) will be considered out of scope of the DFMD, while another time interval becomes part of the period being considered (see figures 1 and 2). Secondly, there are changes in the forecasted maintenance demands within the scope being considered. In other words:

there are new insights in the amount of maintenance being predicted. These may be caused by changes in the asset base, maintenance being postponed or executed early, policy choices, (un)favourable weather conditions, innovations, etc.

Figures 1 and 2 also illustrate the importance of subsequent analysis of data. The development of the DFMD can provide certain insights, but more specific data might better help in explaining what causes changes in the DFMD. More on this in the next subsection.

Another important aspect to consider is that the DFMD can be monitored and compared in various ways. This is shown in the table below.

**Table 1: Overview for monitoring the calculated DFMD over time.**

	Period for calculating DFMD		
	$t_1 - t_{10}$	$t_2 - t_{11}$	$t_3 - t_{12}$
t_0	DFMDt_1-t_0 (t_0)	DFMDt_2-t_{11} (t_0)	DFMDt_3-t_{12} (t_0)
t_1	-	DFMDt_2-t_{11} (t_1)	DFMDt_3-t_{12} (t_1)
t_2	-	-	DFMDt_3-t_{12} (t_2)

In the table above, it is assumed that at t=0, it is possible to determine the DFMD not only for the period of t1-t10, but also for the period t2-t11 and t3-t12. The result is a predicted development of the DFMD (top row in Table 1). One interval (e.g. one year) later, new predictions are available providing new insights in the development. This offers multiple ways of checking the previous predictions with new ones.

3.2 Other indicators

As was briefly mentioned in the previous subsection, the DFMD is unlikely to tell the complete story by itself. Of course, following the values of the DFMD may already provide useful insights, aiding in analysing and in raising questions. According to Perrin (1998), this is one of the purposes of having indicators in the first place. However, it is considered wise not to look at indicators in isolation, but to review them within a set of indicators, preferably complementary and supplementary (de Bruijn, 2007).

One approach for developing a set of indicators is provided by Baird & Stammer (2000). They have developed a conceptual model to systematically use performance indicators. Its underlying principle of the model is the belief that an organisation can be fully described and analysed in terms of input, processes, output and outcomes.
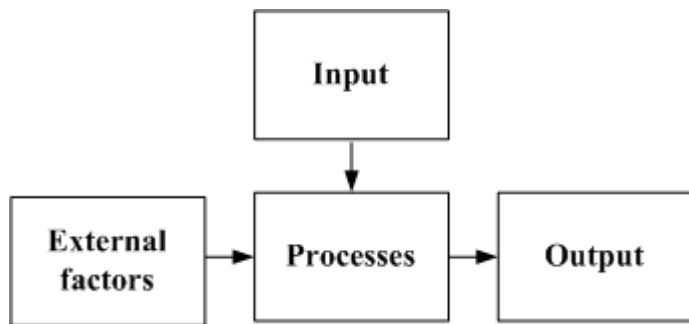
Figure 3:Basic model for describing the processes of organisations (adapted from Baird & Stammer, 2000).

Both from reviewing literature (e.g. Institute of Asset Management 2012, BSI, 2008, ISO 2014) and analysing the processes in the case, it is clear that asset management processes contain many steps such as forecasting, budgeting, planning, programming and executing maintenance works. These steps are closely related, as each process provides input for one or several other processes. Several steps can be expressed in financial values, providing a basis for comparison between other indicators. Therefore, the financial indicators of these steps (e.g., total budgets, total spending) are also related.

It is also clear that each process considers additional input or external factors. In a simplified version, the case (see section 4) could be described in three consecutive steps of forecasting maintenance works, planning maintenance works, and executing maintenance work. The process of forecasting does not consider the (lack of) available financial resources, while the planning process does. Such insights are important to consider for two reasons. The first is to understand what the indicator value means. For example, the DFMD was determined based on forecasting data, thus it should provide a prediction of the maintenance that is technically required. The second reason is that we need to understand that decisions made in these process steps also affect the future maintenance demand. Ideally, it would be possible to see the effect of each asset management process and decision on future maintenance demand. Comparing resulting DMFD's could show the effect of each maintenance decision.

By reviewing the processes in the case, several additional indicators were identified. These are: yearly forecasted maintenance demands, yearly available budgets, yearly planned maintenance works, yearly actual money spend. These additional indicators were used in data analysis and in the case study (simulation).

4 TESTING THE INDICATORS: A DUTCH CASE STUDY

Every four years the Dutch ministry of Infrastructure and the Environment and the Dutch Road Agency (Rijkswaterstaat) negotiate a Service Level Agreement (SLA) for the performance of the national roads, waterways and water systems. In this SLA, the required performance of the infrastructure, the risks and the maintenance budget for the coming four years are agreed upon. Long term consequences are considered in these negotiations, but no indicator is currently used for this purpose. The case was therefore considered an excellent testing ground for the indictor developed.

4.1 *Scope and collection of data*

The methodology was tested for two subsets of the asset portfolio maintained and operated by Rijkswaterstaat: pavements and structures in the national road and waterways network. The scope was limited to the main maintenance aspects, excluding routine maintenance. The main reason for limiting the scope to pavement and structures was availability of data. For both types of infrastructure Rijkswaterstaat maintains information systems that could be used to forecast maintenance amounts more than ten years in advance.

One of the conditions was to rely as much as possible on existing data and information systems. The data held by the available systems were built to store inspection data and to support maintenance planning, not to support long term maintenance demand and cost analyses. Careful interpretation of the results is required.

The data could successfully be gathered from the information sources covering multiple years, making it possible to calculate and follow developments in the DFMD over time, as well as the yearly predicted maintenance demands, available budgets and actual maintenance expenses. However, several issues occurred in making cross-comparisons between the data sources, which are related to the various data sources used having different data definitions. For example, some systems provided total costs while other systems only presented a subset of these costs, excluding some types of maintenance or cost factors.

For practical reasons, in this research, the data sets were used as-is, while taking note of the variety in data definitions. After all, the aim was to find a practical indicator and the opportunities for using this indicator in the decision making process, not to design a completely new data system to get the 'ideal' values for the indicator.

4.2 Setup of simulation of SLA evaluation

A simulation was developed to evaluate the practical use of the DFMD with real data. In a workshop setting, the process of a SLA evaluation was simulated. The people attending the workshop were a cross-section from Rijkswaterstaat including policy makers, maintenance schedulers, financial experts, and people that were involved in the SLA negotiations.

The workshop was split up into different phases. Each phase focused on a specific moment in time, such as yearly reviews of the budgets being spend. Gathered data were presented to the participants, only showing the information that would be available at that moment in time. The simulation covered a two year period in total.

Some of the people from the group were instructed to also look at the results from the perspective of the ministry of infrastructure, to have all relevant actors represented in the simulation. The aim of this simulation was to determine how the DFMD could be of additional value in SLA negotiations. The next subsections show the results of the simulation done for structures.

4.3 Results of the simulation for structures

4.3.1 Phase 1: moment prior to simulated SLA period

During this phase, the participants were shown the forecasted future maintenance demands, and the DFMD that was be calculated from the available forecasting data (figure 4). The forecast shows a significant increase in maintenance demand is expected in the second SLA-period (which covers year 5 to year 8).
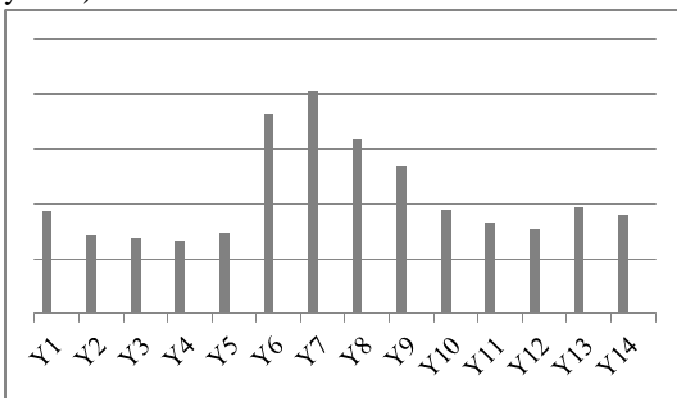
Figure 4: Forecasted maintenance demands, as seen from year 0.

Based on the forecasted yearly demands, the DFMD was also determined for multiple future periods. The values have been indexed and shown in table 2. These values form the baseline of what is expected in terms of DFMD development during the SLA-period.

Table 2: Calculated DFMD, based on forecasting data from year 0.

| | Period for calculating DFMD for structures | | | | |
	y1–y10	y2–y11	y3–y12	y4–y13	y5–y14
Y0	100%*	100%	101%	104%	107%

*figures are indexed, the DFMD for year 1 to year 10, as seen in year 0, is considered 100%.

During the simulation, particular attention was paid to the development of the DFMD for year 5 to year 8. In the simulation, year 5 marked the starting year for the second SLA period. The decisions made during the SLA period of year 1 to year 4 could affect the DFMD for year 5 to year 8. In other words: the DFMD for year 5 to year 14 would give an indication of the long term effects from the first SLA.

Based on the forecasts, the participants expected an increase in the DFMD of seven percent for year 5 to year 14 compared to the DFMD for the period year 1 to year 10.

4.3.2 Phase 2: moment after SLA-negotiations

During this phase of the simulation, the available budgets were known to the participants. The participants needed to determine if the available budgets would be sufficient for executing the forecasted maintenance demand. This proved to be difficult because the budget figures accounted for several cost factors that were not included in the figures of the forecasted data. Compared to the forecasted demand for the SLA period however, budgets seemed to be sufficient.

Given the assumption of sufficient budget, there was no need to adjust the expectations of the DFMD. Logically, if budgets would be considered insufficient, one might argue that the MDFM for future periods would increase (maintenance would be postponed and start to build up).

4.3.3 Phase 3: one year into the SLA-period

One year into the SLA-period, new facts and forecasts would become available to the participants. For one, the actual amount of money spent on maintenance would be known. This was shown to the participants. It showed that around 89 percent of the available budget was spend during the first year. The participants came up with several explanations, among others: favourable market conditions driving prices down, or that some maintenance was not executed or spend on other maintenance work not in these figures. While the first explanation would mean that forecasted maintenance would have been done (only cheaper than expected), the latter explanation would mean that maintenance would still need to be done.

The participant were then asked if they thought that the expectations of the DFMD should be changed due to newly presented information. How-

ever, this was not possible to determine since the explanations provided could both result in a higher and lower expected DFMD.

One year into the SLA period also meant that new forecasting data would become available, this is shown in figure 5. The figure illustrates that overall, more maintenance is being predicted for the foreseeable time (particularly for the years 10-11). An explanation was hard to provide based on this figure alone. The previous mentioned aspect that some maintenance works might not have been done (not all budget was spend) could account for some increase, but would not explain the overall increase across many years. However, it did become clear that answers might be found by specifically focussing on the differences noticed in the data.
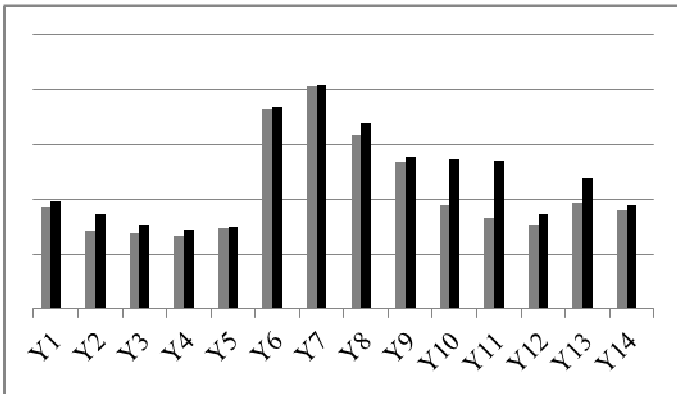
Figure 5: Forecasted maintenance demands. Dark grey represents the forecast, as determined in year 1.

As a direct result of the higher amounts of forecasted maintenance demands, the DFMD also increased (see table 3).

Table 3: Calculated DFMD, including the data based on forecasts from year 1.
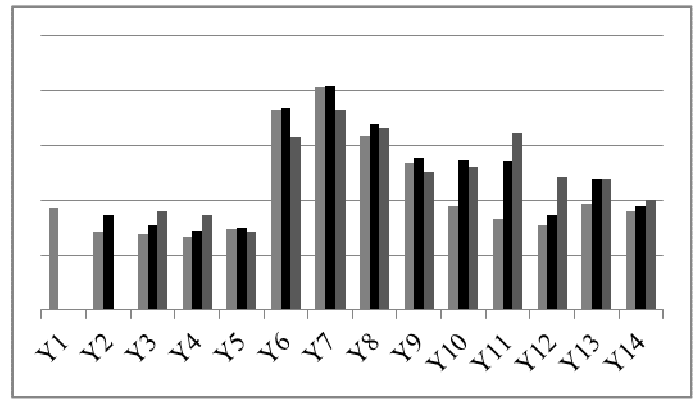
| | Period for calculating DFMD for structures | | | | |
	y1–y10	y2–y11	y3–y12	y4–y13	y5–y14
Y0	100%*	100%	101%	104%	107%
Y1	-	112%	113%	117%	120%

*figures are indexed, the DFMD for year 1 to year 10, as seen in year 0, is considered 100%.

4.3.4 *Phase 4: two years into the SLA-period*

Similar to the previous sub-section, another year passed in the simulation. Again, the actual spending would become known. During the second year, 95 percent of the available budget for that year was spend. Moreover, new forecasting data would become available, shown in figure 6.

The forecast showed similar results as the previous two forecasts, although there were several noticeable changes. The forecasted maintenance demand for the years 6 and 7 decreased while increasing for the years 11 and 12. It showed that the maintenance demands seemed to 'level'. Again, new expectations of the DFMD could be presented.

Figure 6: Forecasted maintenance demands, with a third set of maintenance demands being shown, based on forecasting data from year 2.

Table 4: Calculated DFMD, including the data based on forecasts from year 2.

| | Period for calculating DFMD for structures | | | | |
	y1–y10	y2–y11	y3–y12	y4–y13	y5–y14
Y0	100%*	100%	101%	104%	107%
Y1	-	112%	113%	117%	120%
Y2	-	-	113%	116%	119%

*figures are indexed, the DFMD for year 1 to year 10, as seen in year 0, is considered 100%.

What can be seen from the data is that the original expected DFMD for the period year 5 – year 14 seems to have been underestimated at the start of the fictive SLA. Two years into the SLA (the end of the simulation), it seems that the DFDM for year 5 – year 14 will be 120%, instead of the earlier predicted 107% (an relative increase of 11 percent). There may be many causes to this increase, other than effects of delayed maintenance. Examples of other influences are, for instance, inflation correction on unit prizes, the developments of inspection procedures leading to an earlier risk detection and more explicit inspection results.

Due to lack of available data, the simulation could not be continued to cover the whole of the SLA-period, but the simulation still showed how some of the indicators could be used in the simulation and thus in practice.

4.4 *Summary of the simulation for pavements*

The simulation was also performed for pavements. This proved to be more difficult, mainly due to the nature of the forecasting data. The data showed many irregularities, which made comparing forecasts difficult. The data used came from a planning tool which was specifically designed for that purpose (planning), and the results of this tool are subsequently used in other tools to deliver the final maintenance plan. For providing reliable forecasts for the next 10-15 years, this tool seems to be less

useful. Also, it was found that the yearly maintenance demands for pavement is highly influenced by external factors. For example, bad winter conditions may significantly speed up degradation processes, leading to serious changes in the forecasted yearly maintenance demands.

Still, the simulation was able to make changes in forecasts and DMFD visible, fuelling the discussion on what causes these changes.

4.5 *Reflection*

The presentation of the indicators did not provide many conclusive answers, although the participants did mention it helped raising the right questions. The simulation in this paper showed a significant increase in the expected DFMD, but too little is known to pinpoint main causes for this increase. In this sense, the indicator is still too immature to be used to hold an organisation accountable.

In part, the encountered difficulties can be attributed to the lack of having certain information sources and some limitations in making comparisons (due to varying scopes of information sources). Furthermore, it should be noted that the indicators are highly abstract. However, the indictors did seem to help the discussion and formulation of hypotheses which can be verified in follow-up studies. In this sense, the indictor seems to function as a way of learning. The participants all considered the simulation useful as it brought together multiple disciplines and actors involved in the processes or Rijkswaterstaat.

It was furthermore found that the process of collecting, analysing and discussing data could be tailored to current reviews on budgets, actual spending, etc. Although some effort was involved in collecting the data the first time, future collecting will likely require less effort.

5 CRITICAL REVIEW

5.1 *Definition of scope of indicators*

As specific scope of 10 year period was chosen for the indicators. Much consideration was put into setting the scope, but it should be noted that the scope is case-specific. For example, if the forecasting data proves to be very unreliable on longer timeframes, a shorter timeframe may be more appropriate. This will depend on the organisation and asset specific context.

5.2 *Data collection & data quality*

One of the starting points was to rely as much as possible on existing data and information systems.

However, the systems used were never developed to accommodate this financial trend analyses. Each system is designed for a particular purpose (e.g., aiding planning of maintenance or budgeting). The methodology proposed here requires input from multiple data sources. This resulted in several issues in cross-comparison of data. This will remain a challenge and it is expected that similar challenges will be faced in other infrastructure asset management organisations.

Several challenges were encountered regarding data quality measures apply integrity, accuracy, completeness (ISO, 2015) and consistency, validity, timeliness, uniqueness (e.g., Neely et al., 1997). For instance, it was found that collection of data required very specific definitions of datasets to ensure the right information was gathered. Another aspect is the accuracy of the data, which still is not clear. This accuracy differs across the asset types and maintenance tasks. E.g., costs and timing of some maintenance tasks are better to predict than others. As a result, the simulation proved much more difficult for pavements than for structures. One suggested course of action is to keep collecting the identified indicators, as more data will help to assess the quality of the data obtained.

5.3 *Complexity of data and processes*

Section two shortly discussed the process model used to describe the processes at the case. A small, very simplistic example was provided. The actual processes and sub-processes observed at Rijkswaterstaat are far more complicated. Moreover, many of the processes are not fixed and continuous improvement leads to adaptions in the processes and used/produced data over time. This provides challenges in collecting, understanding, and learning from the data.

Additional complexity lies within the data analysis. It is of utmost importance to carefully discuss potential effects of trends and decisions before reaching a conclusion or even an hypothesis. For instance, increases in asset base (e.g. more roads or structures being build) were often mentioned as potential causes for the increase in maintenance demand. While the relation between asset base size and maintenance demand is evident, it was ultimately not considered as a likely cause for the 'sudden' increases encountered in the simulation. In practice, maintenance planning goes through several optimization- and prioritization cycles, that not only determined by the technical state, but also by other factors like budget constraints, effects of maintenance on availability and interaction with the surroundings. This argues for having several discussion sessions with participants from different fields, in order to develop sound hypotheses for follow-up investigations.

5.4 Functions of performance measurements

In a performance management system, performance is measured with various indicators. Performance can be measured in order to enable an organization to (1) create transparency, (2) learn, (3) compare, (4) assess, and (5) sanction (de Bruijn, 2007). The functions are listed in order or increasing impact for the party whose performance is measured. It is important to be aware of the impact of performance management. The higher the impact, the higher the propensity for strategic behaviour. Such behaviour may lead to perverse effects and unwanted outcomes (Pidd, 2005; Smith, 1995). The higher the impact the higher the required quality of the indicators. Use of the DFMD indicator, at least in the current state of development and use, is only considered suitable for creating transparency and to facilitate learning.

5.5 Top-down versus bottom-up approaches

The work shown here shows a top-down approach. The data collected is on a high abstract level, for example the total amount of money spent on maintenance of pavements. As a consequence, the results do not provide conclusive answers on questions like: too what degree is maintenance being postponed? Many may argue that a bottom-up approach with detailed information is much more valuable. The authors don't argue with this statement, but wish to stress out that such an approach is often not feasible, at least not for the foreseeable future. Detailed information is often scarce or cumbersome to acquire. The simulation illustrates well how even abstract data can support discussion sessions.

6 CONCLUSIONS & RECOMMENDATIONS

Earlier work (Wessels et al., 2014) proved that it is possible to develop a clear, proven, consistent and simple indicator, that represents the long term effect of short term decisions. The application in the case study showed that it is possible to apply the indicators using current existing data and information systems, although several limitations and challenges were encountered. Many asset management organisations may be faced with similar challenges as mentioned in the introduction where there is no measurement system in place to measure the long term effects of short term decision on a network level. Development of such a system will require time, leaving the organisation to wait until results are in. This research shows a practical methodology that enables them to learn based on what they may already have. The authors of this paper encourage anyone to evaluate the possibilities that are presented here.

The work presented in this paper showed the successful further application of the indicator in an simulated environment which is very similar to actual practice. Moreover, the indicator and workshop setting proved a valuable learning ground making use of already existing data. Although there were several limitations encountered, Rijkswaterstaat considers the approach valuable enough to continue on the path of creating transparency and learning. Through continuous collection of data, analysis (including follow-up investigation), more and more insights are gained in the long term effects of short term decisions.

7 REFERENCES

Baird, M. E., & Stammer, R. E. (2000). Conceptual model to support systematic use of performance measures in State Transportation Agencies. Transportation Research Record, 1706, 64-72.

Bouckaert, G. (1993). Measurement and meaningful management. Public Productivity and Management Review, 12(1), 31-43.

de Bruijn, J. A. (2007). Managing performance in the public sector. Utrecht: Routledge.

Institute of asset management, 2012 An Anatomy of Asset Management, issue 1.1, Bristol, United KingdomBritish Standards Institution (BSI), 2008, PAS 55-1:2008 Asset Management Part 1: Specification for the optimized management of physical assets. British Standards Institution (BSI), London, UK.

ISO. (2014). NEN-ISO 55001:2014(E) Asset management — Management systems — Requirements, NEN.

ISO. (2015). NEN-ISO 8000-8 Data quality - Part 8: Information and data quality: Concepts and measuring. Delft: NEN.

Ligtvoet, A., Bhamidipati, S., Herder, P. and Verlaan J. 2013, Life cycle costing bij beheer van infrastructuur netwerken, TU Delft

Neely, A., Richards, H., Mills, J., Platts, K., & Bourne, M. (1997). Designing performance measures: a structured approach. International Journal of Operations & Production Management, 17(11), 1131 - 1152.

Pidd, M. (2005). Perversity in public service performance measurement. International Journal of Productivity and Performance Management, 54(5/6), 482-493.

Schoenmaker, R., & Bruijn, H. d. (2016). Embracing complexity in performance-based contracts for road maintenance. International Journal of Productivity and Performance Management, 65(1), 4-24. doi:doi:10.1108/IJPPM-02-2014-0034

Smith, P. (1995). On the unintended consequences of publishing performance data in the public sector. International Journal of Public Administration, 18(2), 277-310.

Wessels, J. F. M., Schoenmaker, R., van Meerveld, H., Bakker, J., & Schavemaker, J. (2014). Introducing LCC in maintenance decision making on network level. Paper presented at the 4th international symposium on life-cycle civil engineering, Tokyo, Japan.