# Risk Assessment Model based on RAMS Criteria

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**Risk Assessment Model based on RAMS Criteria**

T. (Tânia) C. Viana da Rocha Feiri

University of Twente
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|---|---|
| Author | T. (Tânia) C. Viana da Rocha Feiri |
| Contact | t.c.vianadarocha@utwente.nl |
| Company | Rijkswaterstaat<br>Utrecht, The Netherlands |
| Company supervisors | Jaap Bakker (Rijkswaterstaat, Senior Asset Manager)<br>Dr. Rob Schoenmaker (Rijkswaterstaat/ TU Delft, External Consultant) |
| University supervisors | Dr. Andreas Hartmann (University of Twente, CTW, Associated Professor)<br>Dr. Irina Stipanovic (University of Twente, CTW, Assistant Professor) |
| Program committee | Dr. Andre Doree (University of Twente, CTW, Head of Department)<br>Dr. Hans Voordijk (University of Twente, CTW, PDEng Program Director) |

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# CHAPTER 1. CONTEXT AND PROBLEM DEFINITION

## CONTEXT

In recent years infrastructure asset management (IAM) has been applied as a strategic governance approach to achieve more value from assets by making use of less resources. By combining engineering and economic principles with sound business practice, asset management strives for cost-effective investment decisions throughout the life-cycle of infrastructure assets (Tao et al., 2000).

However, in the arena of transportation infrastructure, agencies are facing increasing challenges with impact on their decision-making processes. On the one hand, the demand is growing; the public becomes more critical on the quality and service that transportation agencies provide; also weather-related influences are changing. On the other hand, the funding available for interventions becomes more volatile. Transportation agencies do not know any longer on how much budget they can count on over an asset lifecycle. To deal with those challenges, transportation agencies have been adopting risk-based approach of IAM, which includes risk assessment and prioritisation for planning inspection, maintenance, repair or replacement actions (Stewart, 2001). By combining this approach with lifecycle costing or other IAM decisions, transportation agencies can quantify the expected cost of a decision in a risk-oriented manner.

One of the key aspects of any decision process under a risk-based asset management approach is the acquisition of reliable and useful data. The information that is drawn from data is essential for cooperative, informed and efficient decision-making processes within organisations. However, the quality of data depends on the inherent processes of gathering, retrieval, storage, analysis and on the way that such data is communicated. Thus, transportation agencies are becoming aware of the importance of have a clear understanding about the information derived from data available “in house” through the use of individual management systems.

In The Netherlands, the management of highways, water and waterways infrastructures is the responsibility of Rijkswaterstaat (RWS). By acting on behalf of the Dutch National Government, RWS has also adopted and implemented risk-based asset management as a governing approach for the management of their physical assets.

RWS has multiple individual management systems for storing data related to different asset types, which in turn, are used to support multiple decision processes. One of those management systems is Data System Works (DISK) that stores inventory, condition, risk and maintenance data of civil structures, such as bridges, tunnels, viaducts or dams.

Based on a perceived gap between the data available in DISK and the risk-based data that maintenance decision-makers would like to have, this report presents a risk-based model designed to support maintenance programmers to select maintenance strategies for individual civil structures. The study is the result of collaboration project between the University of Twente and RWS and is part of a Professional Doctorate Programme (PDEng) in Civil Engineering offered at the department of Construction Management and Engineering.

### OUTLINE

This report is organised as it follows:

Chapter 1 characterises the problem addressed to this study.

Chapter 2 provides the theoretical foundations needed for the design of the risk-based model.

Chapter 3 describes the current asset management practices within RWS and identifies the potential for improving the existing DISK data system. It also presents the requirements for the model derived from a set of interviews to representative practitioners.

Chapter 4 presents the risk-based model and gives a detailed explanation of its constructive blocks.

Chapter 5 provides the main conclusions, limitations and recommendations for further developments of this study.

## RIJKSWATERSTAAT: MISSION, GOALS AND RESPONSIBILITIES

By acting on behalf of the National Government of the Netherlands, RWS is responsible to manage three national transportation infrastructure networks, as it is illustrated in Figure 1.1: highways, waterways and water systems. RWS bases its societal responsibility towards the citizens of The Netherlands through a four-point mission: (1) to guarantee dry feet; (2) to ensure sufficient and clean water; (3) to promote a smooth and safe flow of transportation traffic and (4) to provide reliable and useful information.

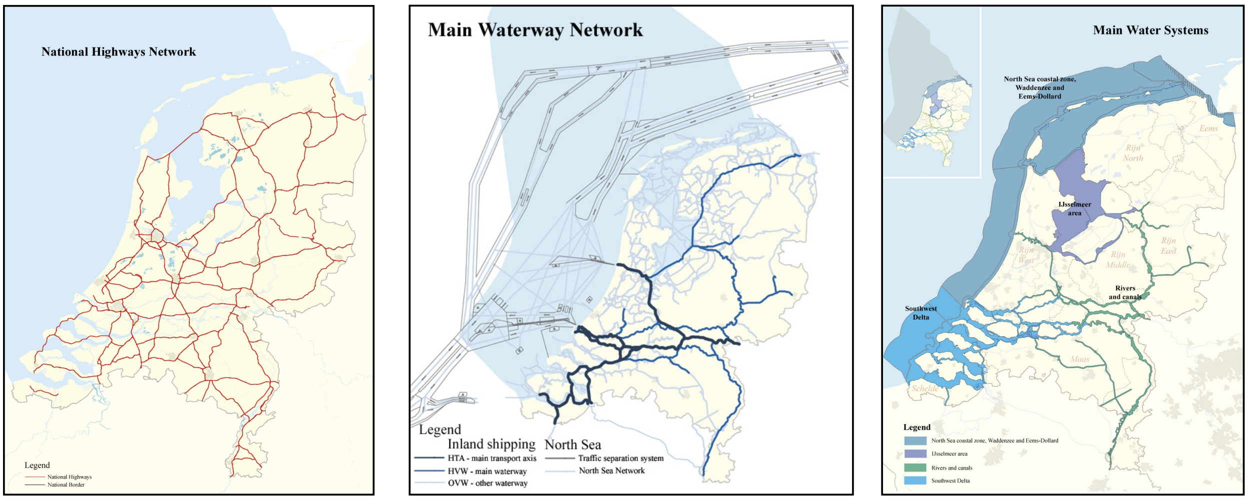



Figure 1.1 - National infrastructure networks responsibility of RWS (RWSa, 2012)

The main goal of RWS is described by Van der Velde et al. (2013) as: *"to deliver best service to the public at lowest life cycle cost, given public acceptable risk"*. While the National Government, as the asset owner, has a role at the strategic level, the service providers, as private contractors and engineering firms, act at the operational level. With the function of asset manager, RWS links the strategic interests of the National Government - in terms of performance, costs and risks – to the operational implementation of such interests. Figure 1.2 shows the main responsibilities of these parties: asset owner, asset manager and service provider.

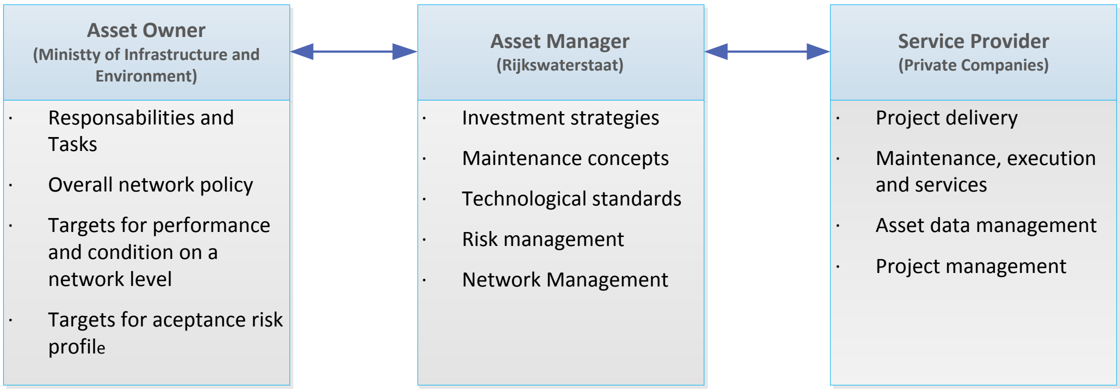



Figure 1.2 - Asset Management roles and the main activities of asset owner, asset manager and service provider (van der Velde et al., 2013)

## PROBLEM DEFINITION

DISK is at the core of the problem addressed in this study. In early stages of this project, some DISK data users expressed concerns related to the effective support of DISK data to multiple asset management decision processes. These concerns were firstly based on the perception that the processes that guide the collection, storage and usage of DISK data are not completely clear. These data users believed that the problem is related to the flow of risk-based data needed for decision support; in fact, practitioners claimed they lack a good understanding of how and when is data collected, stored and used. In addition, the current risk criteria - RAMS SHEEP - used during the risk-based approaches are not well understood by all the practitioners involved in the processes of inspection and maintenance programming. These users highlighted that some of the data collected and stored lacks vital properties for a decision based on risk. Also the identification of decision-processes that demand this data seems to be somehow vague. Figure 1.3 illustrates the described perceptions.

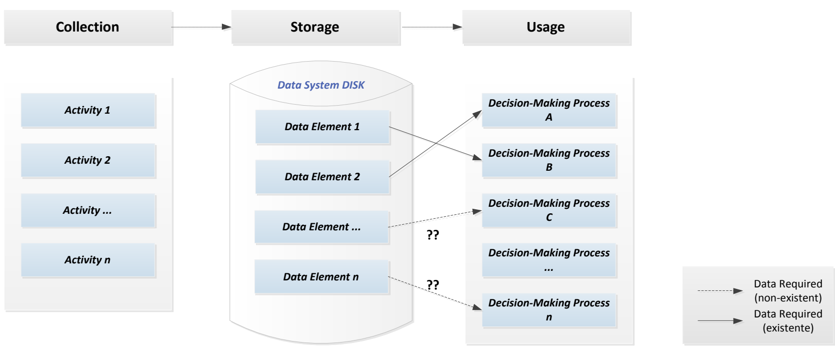



Figure 1.3 - Scheme of problem perceptions: data flow and processes of data collection, storage and usage

Based on these perceptions, the problem identified involves two core aspects. Firstly, the support of risk-based decisions are affected by the way that data is collected, stored and used. Such processes seem to be affected by multiple challenges related to the conversion of risk-based data into useful information that can be used in decision-processes. Secondly, there are also doubts regarding the properties (or requirements) that such risk-based decision processes demand from data (i.e. how must data be presented). Figure 1.4 illustrates these two perspectives.

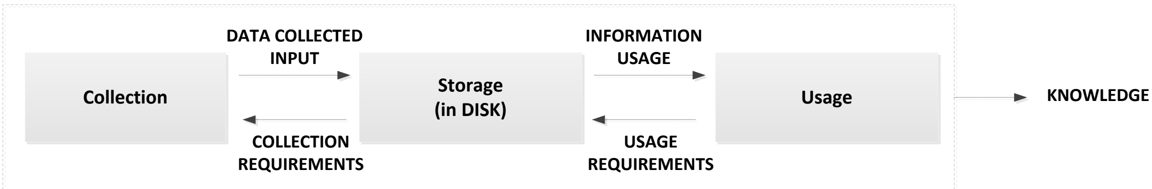



Figure 1.4 - Problem definition: flow of data and information input vs. the respective requirements

## PROJECT OBJECTIVES

The main objective of this project is to design a risk assessment model for civil structures based on RAMS criteria. To this end, through this project we aimed to cover the main sub-objectives as it follows:

1. identify the current capabilities of DISK;

2. identify and evaluate the potential for improving the collection, storage or usage of DISK data in a risk-oriented manner;

3. validate and verify the model among representative data users.

## PROJECT METHODOLOGY

Design projects related to business problems aim to improve the performance of a specific business system or organisational unit. Design-focused problems are rarely solved with rational steps, as opposed to other activities, such as technical or economical. Instead, they are approached through organised phases towards the delivery of the intended performance improvement.

To support the designing process, Van Aken et al. (2007) explained that design-oriented approaches involve five main deliverables, as it is shown in Figure 1.5.

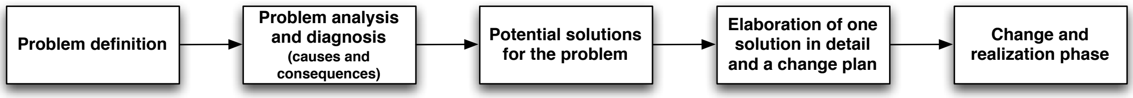



Figure 1.5 - Possible deliverables of a business problem-solving project (Van Aken et al., 2007)

In this context, Van Aken et al. (2007) added *"the basic cognitive activities in a business problem solving project are **analysis** and **design**"*. These researchers highlighted that such activities are quite different in nature since during *analysis,* the dominant logic goes from question to answer while during *design,* it rather goes from solution to specifications to which the solution should conform. Yet the design phase involves a creative leap towards a possible solution. This makes the design an open-ended step since various solutions might be possible and it is not possible to predefine a route from problem to solution. Therefore, Van Aken et al. (2007) suggested an iterative cycle of comparison between the expected behaviour and performance of the proposed business system and the specifications defined to the design (Figure 1.6).

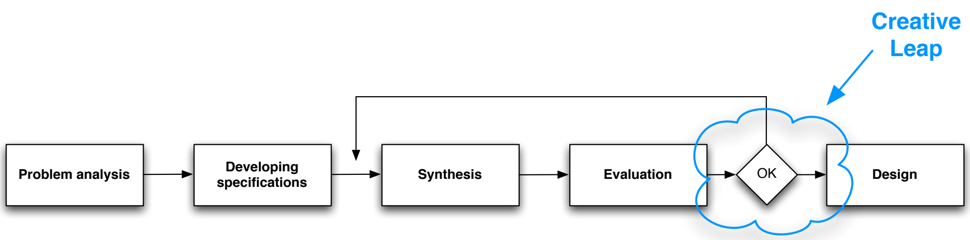



Figure 1.6 - Key activities in the designing process (adapted from Van Aken et al., 2007)

Based on these theoretical concepts, we developed a contextually driven design-oriented methodology to support the design process required in this project, as it is illustrated in Figure 1.7. The project methodology is described below.

### Problem analysis

The problem analysis phase includes the preliminary assessment of the problem as perceived by some data users and the assessment of the current asset management practices within the organisation. This phase required a continuous interaction with DISK data users and a desk-based analysis of the internal documentation and procedures. We studied the structure and content of the existing DISK database and all the processes that support the data collection, storage and usage.

More, we assessed the current state-of-the-art of risk and its concepts and we analysed literature about RAMS criteria and about uncertainties under decision-making.

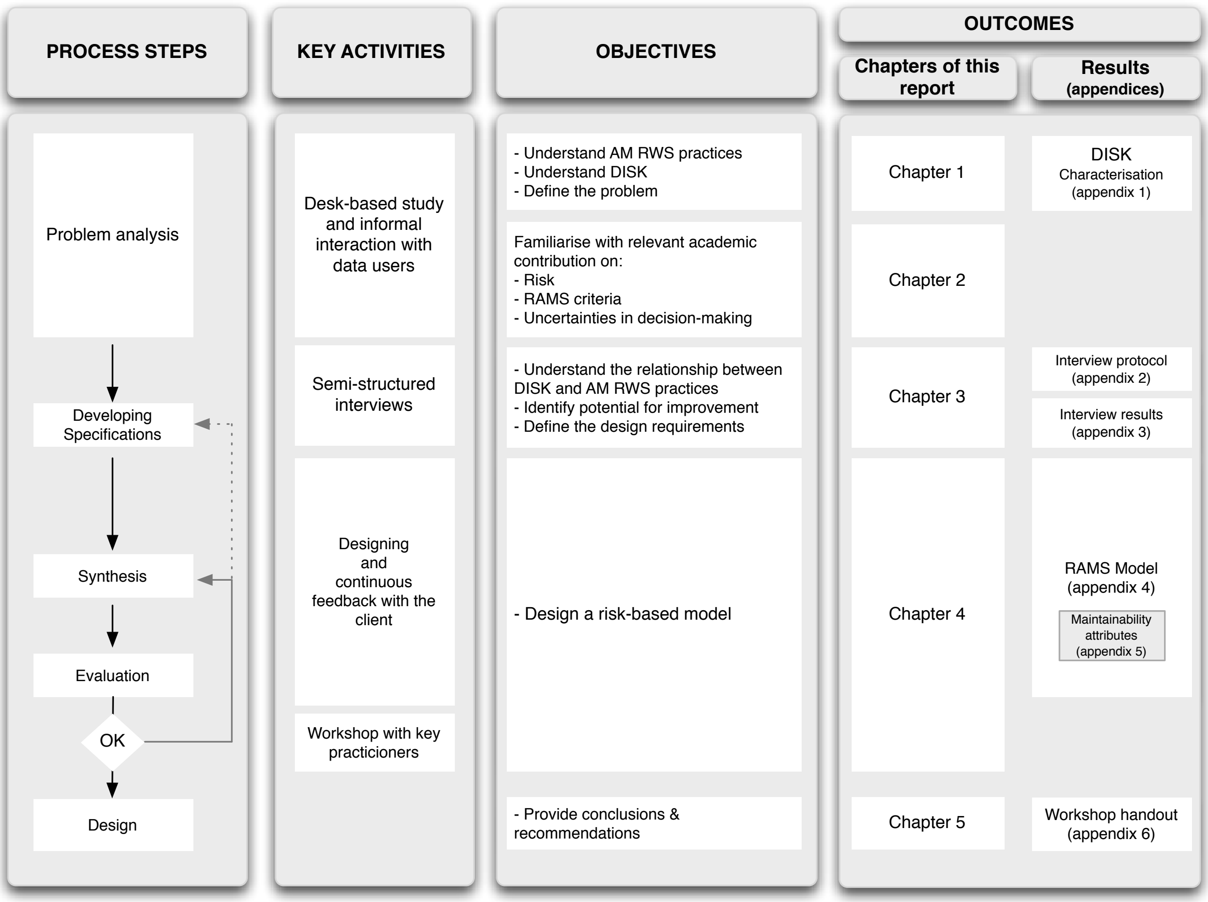



Figure 1.7 – Project methodology

### Developing specifications

This phase aimed to identify and specify the functional specifications needed for the risk-based model (i.e. design requirements). Such requirements acted as the verification and validation aspects that guided the design process. We focused on the two preliminary user perceptions defined during the problem analysis to identify the potential for improving the data collected and stored in DISK and the processes that use that data.

The first perception regards the way people behave under conditions of uncertainty during a decision process (i.e. the behaviour adopted during the use of data in a specific decision-making process). The second perception concerns the characteristics of data used: data quality. The analysis of these perceptions cannot be done separately since, to some extent, their scope overlaps. For example, the sources of uncertainties in a decision process might be related to the properties of data, might be caused by the manner decision-makers use data or might be the result of the way that data is interpreted or understood.

By taking into account such preliminary perceptions, we conducted a set of interviews among representative DISK data users. The goal was to understand the challenges associated with data collection, storage and usage and to assess their perception about the quality of data. Figure 1.8 illustrates the process scheme used during these activities to identify the potential for improvement.

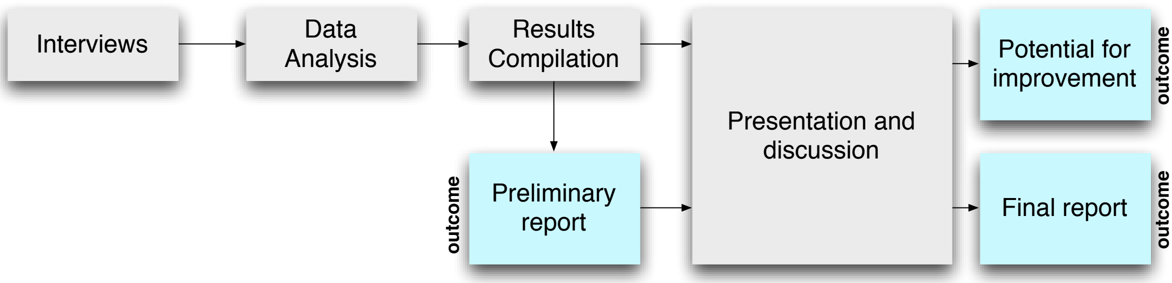



Figure 1.8 – Process to identify the potential for improvement

### Structure of the interviews

The data collection process was based on a set of semi-structured interviews. The added value of a semi-structured interview is the allowance of new ideas to be brought during the interview. To provide guidance to the interviewer, it was prepared a protocol with a group of questions and sub-questions.

### Characterisation of respondents

Between 06.12.2013 and 06.03.2014, we performed fourteen interviews involving a total of eighteen respondents. Each respondent had functions in one of the decision processes selected: inspection and maintenance advice process or maintenance programming process. Table 1.1 characterises the the set of respondents.

Table 1.1 – Characterisation of respondents

<table>
<tr><th>DECISION PROCESSES</th><th>ORGANIZATIONS</th><th>FUNCTIONS</th><th>NUMBER OF INTERVIEWS</th><th>NUMBER OF PARTICIPANTS</th></tr>
<tr><td>Inspection and maintenance advice</td><td>Private engineering firms</td><td>Inspectors/ Engineers/ Consultants</td><td>3</td><td>5</td></tr>
<tr><td>Maintenance programming</td><td>RWS Regional</td><td>Maintenance programmers/ Asset Managers</td><td>7</td><td>9</td></tr>
<tr><td>Inspection and maintenance advice</td><td rowspan="2">RWS Central</td><td rowspan="2">Inspection coordinators/ Programming coordinators</td><td>3</td><td>3</td></tr>
<tr><td>Maintenance programming</td><td>1</td><td>1</td></tr>
</table>

### Method of data analysis

The interviews were recorded and analysed in a chronological order. The perceptions provided by the practitioners were categorised in underlying themes. An overall portrait of the results was constructed.

## Synthesis and Evaluation

After the identification of design specifications, the design process involved the steps of synthesis and evaluation. To some extent, these steps are strongly inter-winded. *Synthesis,* in the immaterial world of communication, involves drawings and texts of the entity to be realised; it is followed by an *evaluation* of the expected performance of that entity against the design specifications on the paper (i.e. also is in the same immaterial world). These steps are mainly based on iterations (i.e. going to a previous step) and explorations (i.e. be briefly jumping to a step further on in the process to explore possible design solutions). The result of such exercise is an outline design, which is a formal design containing all the design decisions with respect to the key of the design dilemmas.

In this study, the steps of synthesis and evaluation involved a continuous interaction with the academic and organisation professionals participating in the study. This interaction was made through frequent feedback meetings and discussions, which essentially aimed at:

- validating the outline design with respect to the design specifications;
- identifying potential limitations of the outline design at stake; and
- analysing potential drawbacks or barriers for the model's implementation.

This phase ended with a final workshop with representative DISK data users (RWS and service providers - engineers/ inspectors).

### Design

The design process ended with the production of the design model (risk assessment model), which is a prototype validated by the client and representative data users.

## SCOPE AND DELIMITATIONS

The scope of this project is limited to the data collected, stored and used in DISK (i.e. data related to civil structures). The analysis and evaluation of other data management systems (individual or collective) are not considered part of this project. In addition, we limited this study to the analysis of the RAMS aspects; the SHEEP extension was not considered. More, the internal asset management concepts, models and business processes are not analysed for the purpose of changes or adjustments. For the sake of this project, these concepts, models and processes are considered optimal to accomplish the mission and goals established by RWS.

# CHAPTER 2. CONCEPTUAL BACKGROUND

## RISK AND ITS VARIATIONS

### Traditional concept of risk

Risk is a rather commonly used notion that is applied interchangeably with words like chance, likelihood and probability, to indicate that we are uncertain about the state of an item, issue or activity under discussion (Faber & Stewart, 2003). Traditional techniques to assess risk are mainly based on probabilistic approaches, which combine probabilities of an event with its expected consequences. Considering an activity with only one event (i.e. hazard or threat) with potential consequences, risk (R) is the probability (or likelihood) (P) that a specific event will occur, multiplied by the consequences given the event occurs (C), i.e.:

(1) $R = P \times C$

However, the definition of risk is not always a precise and consistent term since other factors can be addressed. For example, the Transportation Research Board of the USA (TRB, 2009) makes reference to a new factor to characterise risk: vulnerability (V). Vulnerability is a measure of relative susceptibility to the consequences of a hazard or threat. Thus, according to TRB (2009), risk is determined as a function of those three elements, i.e.:

(2) $R = P \times C \times V$

Despite the risk concept lacking a common definition, analysis, treatment and regulatory requirements of risk, as well as the nomenclature, each discipline seems to adapt the risk concept to their own needs (Faber & Stewart, 2003). Such adjustment seems to be valid for the context of transportation asset management, where the risk concept is also assuming different perspectives.

### Risk seen from different perspectives

In the context of transportation asset management, risk is usually the combination between the probabilities of an object failure with the overall consequences (or impacts) of that failure (Bush et al., 2013). Failure is here understood broadly as any situation when an object does not fulfil its performance expectations or targets (Faber & Stewart, 2003). This may, in extreme and rare cases, be the same as structural collapse or damage, but may also include non-catastrophic failures, such as object's functional deficiency.

Bush et al. (2013) classified the consequences of failures in two main categories: (i) direct consequences, including maintenance, repair or replacement costs and (ii) wider consequences, including whole networks or regional level consequences; examples of these consequences are traffic delays, service interruption, loss of business, loss of heritage or iconic status, just to name a few.

Literature related to risk-based approaches in civil engineering shows that an asset performance is often expressed in a reliability-based format (i.e. structural reliability). A reliability-based technique aims to define structural safety and provides a measure of risk by which safety, cost-effectiveness and other asset management considerations can be measured and compared with each other for future maintenance interventions (Stewart, 2001). In this format, a reliability index is defined as a time-dependent measure of asset structural safety. Probabilistic risk analysis methods are the basis of this approach, since they can provide quantitative tools for the management of uncertainty in condition assessment (Ellingwood, 2005). In a practical way, risk is frequently linked to uncertainties involving structural assessment based on (structural) strength and deterioration mechanisms; typically involves the probability of structural failure, reflected in terms of collapse or serviceability (Frangopol et al., 2001; Stewart, 2001; Ellingwood, 2005). Literature related to structural engineering is filled with multiple examples of reliability-based techniques. For example, Stewart (2001) presented a reliability-based assessment of ageing bridges using risk ranking and life cycle cost decision analysis by making use of structural reliability data (e.g. load models and resistant models). In 2003, Adey et al. presented a risk-based approach to determine the optimal maintenance interventions for bridges affected by multiple hazards. The approach requires the assessment of the likely structural levels of service, the evaluation of the probability of having these levels affected by a set of hazards and the respective consequences of those hazards on each level of service. Ellingwood (2005) presented an overview on a risk-based approach to manage the structural ageing problem based on time-dependent reliability assessment.

However, maintenance decisions often face situations where different attributes need to be considered concurrently. For example, a damage resulting from an accident may lead to a wide-ranging set of consequences such as costs, human casualties, financial, community disturbances, damages to the environment or, on extreme situations, political effects. In addition, different interest groups may have distinct objectives, and thus, in effect, value the combined effect of the attributes differently (Faber & Stewart, 2003). By considering this challenge, Faber and Stewart (2003) suggested a risk assessment overview for civil engineering facilities. Such risk assessment takes into account the possible impacts that an accident may have, aggregates several dimensions of consequences and incorporates the decision-maker's preferences and behaviour in cases or uncertainties within a clear and mathematical-based risk measurement. However, this multi-attribute decision model has drawbacks since it does not provide any answer to how the different attributes and objectives should be weighted.

Another example comes from the Transportation Research Board of the USA, which defined a risk management methodology for transportation systems primarily consequence-driven (TRB, 2009). The initial emphasis on consequences guides the user to focus on outcomes rather than on particular assets or threats. Users do not need to know the cause for the loss or the scenario that led to the loss. The consequence-driven methodology evolves from a desire to limit required inputs to information accessible to users, which, to the extent possible, is objective in nature. The focus is given to the loss of asset's use.

An additional perspective comes from the strategic management aspect presented in the VTRC (2004). Risk is not always assumed from the low-level point of view, with material and structural degradation of assets or networks. In such low-level, a single-objective approach may compromise legitimate, conflicting and non-commensurate objectives. By being grounded by principles of risk-cost-benefit modelling, on the use of resources as databases, and on a set of decision-support tools, the VTRC (2004) presented a methodology that incorporates and investigates the risks involved in the asset management of a highway infrastructure system.

Lounis et al (2009) defined a multi-objective approach for the management of managing critical highway bridges. This approach enables a better evaluation of the effectiveness of preservation and protection strategies in terms of several objectives (safety, security, mobility, cost) and determines the optimal solution that achieves the best trade-off between all of them (including conflicting ones, such as safety and cost).

More recently the Federal Highways Administration of USA (2012) presented a formal risk management model to all the levels of an organisation (i.e. agency, program and project). The model is a formal process of strategic risk management, or the management of risks to key agency objectives and policies, including among others: the identification of risks to strategic objectives and their prioritisation, mitigation, communication, and finally, their tracking across the organisation. The model also addresses all sort of strategic risks, such as financial, strategic, operational and hazards and supports change-management and organisational communication practices to be adopted in a large and complex organisation. Among others benefits, the report highlights that the model gives support: (i) to reduce risks to achieve asset performance, (ii) to reduce the risk of poor investment decisions, (iii) to anticipate asset investment needs and contrast them with possible revenues, (iv) to reduce the risk to the value or condition of assets, (v) anticipate external risks to its assets, including natural disasters, major economic downtowns or political changes.

## RAMS CRITERIA: BASIC CONCEPTS

The RAMS criteria (Reliability, Availability, Maintainability and Safety) are defined according to the EN 50126 as *"a qualitative and quantitative indicator of the degree that the system, or the subsystems and elements comprising that system, can be relied upon to function as specified and to be both available and safe"*.

However, while the RAMS concepts are being widely used in other industries, such as on the chemical, nuclear or even on the railway infrastructure, the application of RAMS criteria in the field of civil structures seems to be still limited. Some researchers, as Ogink and Al-Jibouri (2008) explained that many designers in construction do not have the knowledge and experience about how to apply these concepts. Other researchers, as Van den Breemer et al. (2008), explained that an important reason for its wide application in other industries - but scarce use in the construction industry - is related to its association with the Systems Engineering approach. Since this approach has been introduced relatively recently in the construction industry, the application of RAMS within its design practices remains slow and limited. In addition, the RAMS criteria have not always been developed as a unified discipline but as separated engineering practices, such as reliability or safety engineering. The integration of all criteria seems to be only used for new designs, as an attempt to balance benefits against risks and to select a design compromise that balances value enhancement of the whole system against the cost of failure reduction (Smith, 2005). Yet, in the field of civil structures, the use of RAMS for maintenance purposes is still very rare.

For this reason, to guarantee the correct use of these criteria in the field of risk-based inspection and maintenance of civil structures and to consolidate the foundations of the design model, we must understand the scope of each criteria and the mutual relationship between them. Therefore, we revisited some of the theoretical contributions of the RAMS criteria used in different areas of knowledge and analysed the extent to which they were in line with the concepts adopted by RWS.

### Reliability

Reliability is seen by RWS as the probability that a system (a structure) will fulfil its function under certain circumstances, during a specific time interval. While this is a correct definition of the concept, it is somewhat incomplete. Firstly, the definition does not consider the specified limits of performance that the systems and its elements must comply with. In fact, reliability of an item must represent its capability to respond and sustain operation, without failure and under specified conditions during a given period of time.

This leads us to another aspect that must be considered: the relationship between function and failure. Attending to the definition of Stapelberg, 2009, *function* is given as the work that an item is designed to perform, while *failure* is considered as the inability of an item to function within its specified limits of performance. This means that failure is the interruption of an item's functional capability or its loss of performance below the threshold defined in functional specifications. From the definition, two degrees of severity for functional failure can be perceived:

- *a complete loss of function*, where an item cannot carry out any of the work that it was designed to perform.
- *a partial loss of function*, where an item is unable to function within specified limits of performance by losing its performance or characteristics through ageing; as a result, an item can be exposed to failure just below the failure point defined in the functional specifications.

For the analysis of reliability, and before the identification of failures, it is vital that functional performance limits are clearly defined. However, it is frequent that the definition of those limits is not exactly a straightforward task, especially when an object is composed by a large number of structurally dependent elements. In fact, the definition of those limits normally requires that the function of various assemblies and elements are identified and the performance limits are defined in relation to their functions.

A final aspect that is not being directly considered in the definition from RWS is the effect of maintenance on the reliability level. As a time dependent parameter, the reliability of a system decreases over time due to its usage (i.e. ageing). However, the extent of such reduction is determined not only by the physical characteristics of a system and its level of usage, but also on the level of maintenance actions that are applied (i.e. all activities performed on item to assess, maintain or restore its operational capabilities). S. Martorell et al. (2005) analysed such impact of maintenance on the level of reliability by distinguishing reliability in terms of natural and intrinsic properties:

(i) natural reliability is the reliability of an item with no maintenance at all, which depends on its physical characteristics or design.

(ii) intrinsic reliability is the value (i.e. in principle higher than natural) obtained with a normal amount of quality maintenance.

Considering these aspects, for the sake of this study it is adopted the definition of reliability provided by Spatelber (2009), as

> *the probability that an item (i.e. a system or its elements) is able to carryout the work that is designed to perform, within specified limits of performance for a specified interval of time under stated conditions.*

#### Maintainability

Maintainability is perceived by RWS as the probability that a system/structure fulfils its function under certain circumstances during maintenance within the established time frame.

Similarly to reliability, a critical aspect of this definition is the effect of maintenance actions. According to S. Martorell et al. (2005), maintenance on an item introduces two types of positive aspects. Firstly, corrective maintenance restores the operational capability of a failed or degraded item. Secondly, preventive maintenance increases the intrinsic reliability of non-failed item beyond the natural reliability, for example, by controlling its degradation below the failure point. Although an item can be subjected to preventive and corrective maintenance, it may degrade over age depending on working conditions and on the effectiveness of the maintenance action itself. To classify the effect of maintenance on maintainability, Morey de Leon et al. (2012) defined two types of maintainability attributes:

(i) general attributes (or intrinsic): those affecting any device maintenance level or maintenance level independent. Examples are: simplicity, modularity and ergonomics.

(ii) specific attributes (or contextual): those depending on the maintenance level; that means that those attributes are functions of all the maintenance actions to be performed on a specified maintenance level. Examples are: accessibility, assembly/disassembly, personnel training, maintenance tools and item and documentation.

Maintainability is commonly defined as the characteristics of an item's design and installation that provides the ability to be repaired easily and efficiently (Coulibaly et al., 2008). Good maintainability is assumed as a property that allows for an item to be maintained in the quickest possible time by using optimal resources. Therefore, Moreu de Leon et al. (2012) characterised maintainability as a criteria dependent on three main aspects: (i) design, (ii) maintenance staff and working conditions and (iii) logistics support.

However, maintenance also brings an adverse effect to a system: the downtime, as the period during which an item's operational or physical condition is in such a state that it is unable to carry-out the work that it is designed to perform (Stapelberg, 2009). The adverse effect of maintenance can be seen from the maintainability perspective. For example, an object can be designed to have optimal maintainability for preventive maintenance actions, but it might not be well prepared for corrective maintenance.

Considering these aspects, a more accurate definition of maintainability is given in EN50126 as:

> *the probability that a given active maintenance action for an item, under given conditions of use, can be carried out within a stated interval when the maintenance is performed under stated conditions and using stated procedures and resources.*

### Availability

Availability is seen by RWS as the probability that a system/structure can fulfil its function at any random moment under certain circumstances. From the literature, we identified a critical aspect that seems to be somehow loose in this definition: the relationship between failure and function.

Similarly to reliability, the specifications of failure must be considered during any availability assessment. However, availability, or more directly the unavailability of an item, not only depends on the downtime effect. It also depends on the probability of falling to perform its intended function (unreliability effect), since a failure can occur while an item or a system is performing its intended function (i.e. mission failure), at the moment of demand to operate (i.e. on demand) or before the demand (i.e. in stand-by). The later is associated only with safety-related aspects; for example, an item in stand-by can experience failures in such period of time that will remain undetected until what ever becomes first a true demand to operate or a given operational test. Such differences in the definition of failure, gives room to different types of availability (Table 2.1).

Table 2.1 – Type of availability

| AVAILABILITY | DESCRIPTION | DEPENDENCIES |
| --- | --- | --- |
| Inherent Availability | It takes **corrective** maintenance into account and it is defined in terms of Reliability and Maintainability.<br>It is the prediction of an expected system performance or system operability over a period which includes the predicted system operating time and the predicted corrective maintenance down time (Stapelberg, 2009: Conlon et al., 1982). | MTBF: Mean time between failure (Reliability)<br>MTTR: Mean time to repair (Maintainability) |
| Achieved Availability | It considers **preventive** and **corrective** maintenance.<br>It is the assessment of system operability or equipment usage in a simulated environment, over a period which includes its predicted operating time and active maintenance downtime (Stapelberg, 2009: Conlon et al., 1982). | MTBM: Mean time between maintenance<br>MAMT: Mean active maintenance time |
| Operational Availability | It includes **preventive** and **corrective** maintenance, **logistics delay time and administrative delay time**.<br>It indicates the Availability in an actual operational environment (Kawauchi & Rausand, 1999). It is the evaluation of potential equipment usage in its intended operational environment, over a period that includes its predicted operating time, standby time, and active and delayed maintenance down time (Stapelberg, 2009: Conlon et al., 1982). | MTBM: Mean time between maintenance<br>MDT: Mean down time |

For the sake of this study, a more accurate definition of availability is provided by EN 50126 as:

> *the probability that an item will be in a state to perform a required function under given conditions, at a given instant in time or over a time interval, assuming that the given external resources are provided.*

### Safety

Safety is seen by RWS as the absence of unacceptable risks in the system/structure in terms of human injuries. In fact, safety is a complex criteria to quantify due to the diversity of unsafe situations and accidents that can occur. This explains why safety is frequently associated to Risk Analysis, where the risks of a specific situation are identified, the occurrence and impact is determined and the total risk is calculated (Breemer et al., 2010).

Several definitions of safety are available in literature. For example, Martorell et al. (2005) defined it as an item's capability to prevent or mitigate the consequences of postulated accidents. It is done in respect to risk and loss through accidents or incidents resulting from the complex integration of systems and its elements. This risk is a measure of safety defined as the probability of causing damage to users, to maintenance staff or to health or environment. The integration of all of these factors is complex and requires a lot of data, which might not be available at the moment of the analysis. Thus, for the sake of simplification, safety must be consider in relation to the users of the system and is defined as (Martorell et al., 2005):

*the probability of causing damage to the health and safety of the public.*

### Relationship between RAMS criteria

The underlying concept in the RAMS aspects is that each of the criterion cannot be analysed separately. In fact, the norm EN 50126, emphasises such relationship by highlighting the dependency of availability and safety on reliability and maintainability and on operation and maintenance actions (Figure 2.1).

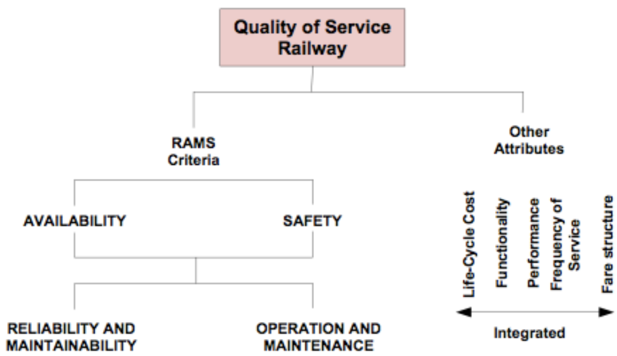



Figure 2.1 – Interrelationship of RAMS elements (Railcorp, 2010: EN50126:2001)

This dependency between aspects is extensively explained in related literature. For example, in Railcorp (2010) is mentioned that the attainment of in-service and availability levels can only be achieved by meeting reliability and maintainability targets and by controlling maintenance and operational activities on the long-term perspective. A practical example in the road rector is that if more traffic load goes on a road than the amount that was predicted in the design phase, more maintenance is needed due to a higher level of degradation, which in turn will decrease the reliability of the road. This relationship is also valid when more maintainability means higher effectiveness leading to a positive influence on reliability (Breemer et al., 2010).

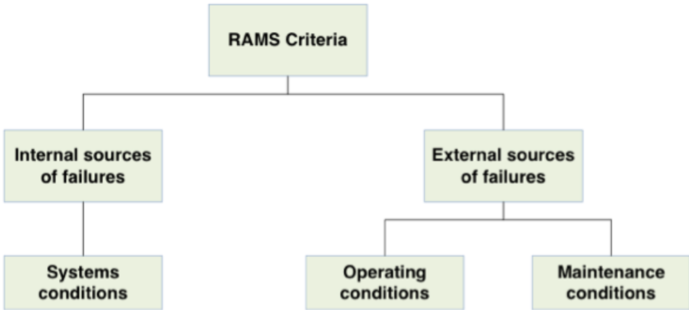



Figure 2.2 – Conditions that influence RAMS (adapted from Railcorp, 2010)

Patra (2007) reflected on the relationship between RAMS criteria and emphasised the role of reliability as a key criteria by mentioning that failures of a system have effect on its behaviour and performance. In fact, also Railcorp (2010) adopted this perspective of failure, which can be categorised in relation to its origin: (1) internal sources of failure inside the system, (2) sources of failures during operation activities of the system or (3) sources of failures during maintenance activities (Figure 2.2).

The study of Patra (2007) shown in Figure 2.3, presents maintainability as the number of failures occurring in a period of time and supportability, in terms of probability and criticality of failure modes of the system. For their turn, maintenance activities affect the performance of a system through maintenance procedures, logistic procedures and human factors. Patra (2007) argues that safety can be considered a sub-set of reliability, when the severity (or consequence) of a failure is taken into account. However, the researcher says that while every failure adversely affects the system's reliability, some specific failures just have effect on the system's safety. Safety depends on maintainability in terms of easy to perform maintenance related to failure modes. It depends also on the maintenance support of a system in terms of effective maintenance procedures to restore the system into a safe mode. Figure 2.3 illustrates these concepts.

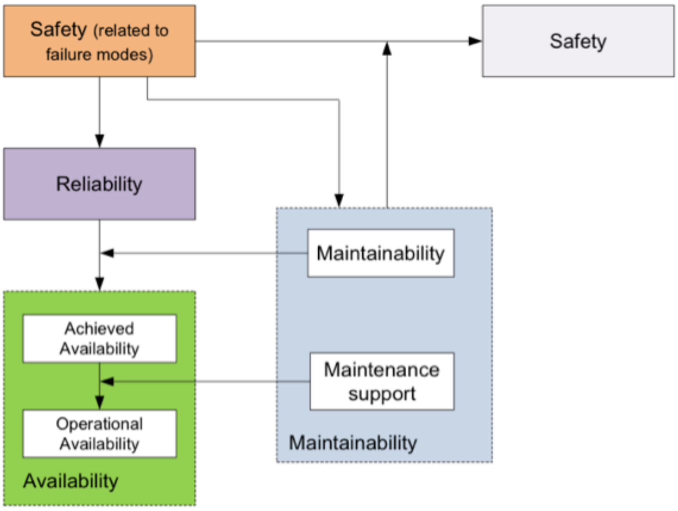



Figure 2.3 – Interrelationship of RAMS elements (adapted from Patra, 2007)

In the context of nuclear industry, S. Martorell et al. (2005) presents a relationship between the RAMS factors, based on a distinction between *natural* and *intrinsic* reliability and assuming safety as a risk resulting from Availability (Figure 2.4).

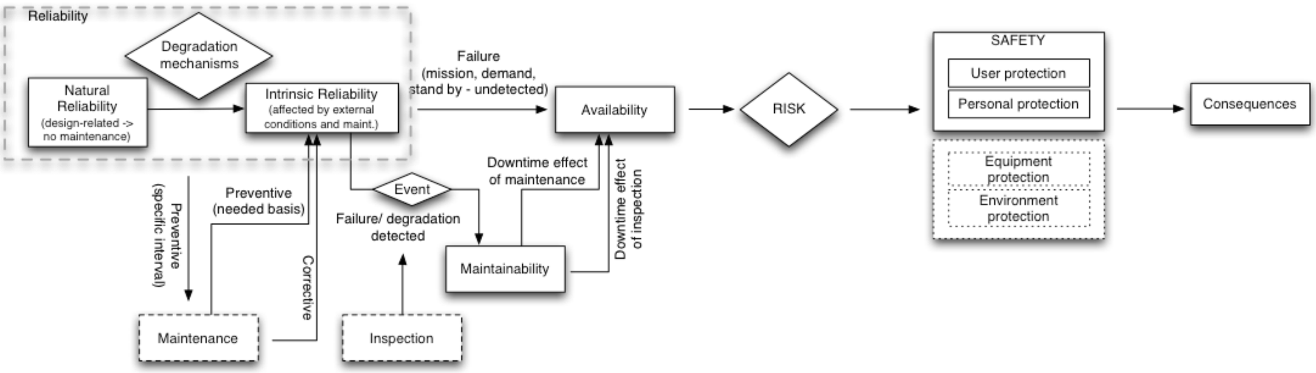



Figure 2.4 – Interrelationship of RAMS elements (adapted from S. Martorell et al., 2005)

## UNCERTAINTIES IN DECISION-MAKING

### Decision-making approaches

In a rational decision-making process, information plays a crucial role to reduce uncertainty; however, information is seldom seen as a deterministic factor during such process (Citroen, 2011). The characteristics of information in management decisions, such as the quality and the source and the actual use of available information, are still not completely recognised as vital elements during the decision-making. This leads us focus on two theoretical approaches that characterise the way decisions under uncertainty are made:

(i) Normative approaches, which explore how people should make decisions (Marold et al., 2012). Lee and Dry (2006) named this approach as *substantively rational inference*, as the optimal approach for human decisions under uncertainty.

(ii) Descriptive approaches, which analyse and describe different heuristics and biases in a decision-making process under uncertainty (Marold et al., 2012). Lee and Dry (2006) named this approach as *procedurally rational inference* (i.e. providing accounts of heuristic process that make fast and accurate decisions based on uncertain information). By discussing the nature of rationality, Smithon and Bammer (2008) explained the concepts of heuristics and biases through the use of irrationality. These researchers defended that mental shortcuts to reasoning (heuristics) used by people cause to fall prey to irrational tendencies (biases). Thus, heuristics and biases explain that individual preferences change all the time and are affected by different factors in relation to the context and situation of decision-making.

As decision-makers systematically violate normative principles, prescriptive interventions are sometimes implemented to support them to get closer to a normative ideal (Marold et al., 2012: Lipshitz & Cohen, 2005).

### Types of uncertainty in decision-making

Lipshitz and Strauss (1997) defined uncertainty as a sense of doubt that blocks or delays action. This initial perception of uncertainty is complemented with three main conceptual propositions (Marold et al. 2012: Lipshitz et al., 2001) (Figure 2.5).

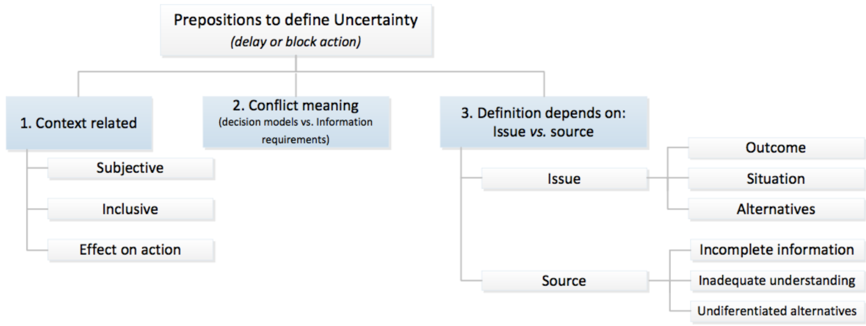



Figure 2.5 – Prepositions to define uncertainty (based on Lipshitz and Strauss, 1997)

Firstly, uncertainty depends on the context of action and has three essential features (i) it is subjective (i.e. different between individuals in similar situations); (ii) it is inclusive (i.e. no particular form of doubt is specified) and (iii) it conceptualises uncertainty in terms of its effects on action (i.e. hesitancy, indecisiveness and procrastination). Secondly, the level of uncertainty existing in a decision process depends on the decision-making model employed. Granted that uncertainty is a sense of doubt that blocks or delays action, models that have different informational requirements will be blocked or delayed by different doubts. Thirdly, different types of uncertainty can be classified according to their issue  (i.e. what is the decision- making uncertain about) and source (i.e. what is the cause of uncertainty).

A more recent approach presented by Ascough et al. (2008) on the context of environmental decision making emphasises that uncertainty is a non-intuitive term that can be interpreted differently depending on the discipline and context where it is applied. These researchers classified uncertainty typologies into four categories (Figure 2.6):

(1) Knowledge uncertainty (epistemic or reducible): it is related to the limitation of our knowledge, which can be reduced by additional research and empirical efforts. It can be labelled as epistemic or epistemological uncertainty and depends on any of these aspects:

- Process understanding: limits of scientific understanding (e.g. what knowledge is lacking or what temporal or spatial scale mismatches existing exist among disciplines).
- Parametric/data: data uncertainty arises from measurement error, type of data recorded and length of record, type of data analysis and/ or processing and the method of data presentation.
- Model structure: the structure of models employed to represent “real-world” systems is often a source of uncertainty; model structure uncertainty arises from the use of surrogate variables, the exclusion of variables, the relationship between variables, input/ output, and from approximations and functional forms, equations and mathematical expressions used to represent the world.
- Technical: it is related to the uncertainty generated by software or hardware errors.

- Model output: it is related to the accumulated uncertainty (i.e. propagated through the model) caused by all of the above sub-categories and is reflected in the resulting outcomes.

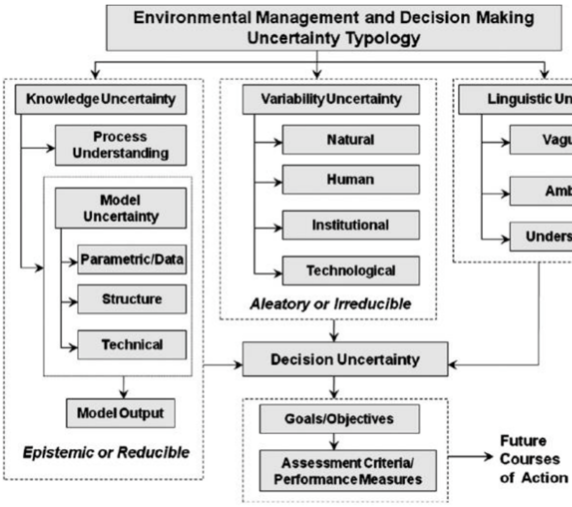



Figure 2.6 – Description of uncertainty in environment management and decision-making based on different types of uncertainty (Ascough et al., 2008)

(2) Variability uncertainty: it is linked to the selection of a particular decision-making approach. This can be classified as external, objective, random or stochastic and is critical in management decisions, since it is usually poorly understood and confused with knowledge uncertainty as a result of ignorance. The components of variability uncertainty are : (i) natural, (ii) human, (iii) institutional and (iv) technological.

(3) Decision-making uncertainties: it is related to ambiguity or controversy about how to quantify or compare objectives. This can be also known as value uncertainty. Decision uncertainties may be related to the way model predictions are interpreted and communicated, especially related to future course of actions. These uncertainties can cause delays of action, or cause the selection of values at the extreme of ranges that results in highly risky (or overly conservative) management decisions.

(4) Linguistic uncertainty: linguist uncertainty is mainly due to natural language, which is vague, ambiguous and context dependent and the precise meaning of the words can change over time. This can be present in model predictions. Vagueness can arise because of natural and scientific language, where a precise description of a quantity or entity is not available. Ambiguity arises because some words have more than one meaning, and it is not clear the meaning that it is intended. This uncertainty can arise as a result of epistemic uncertainty.

### Strategies to handle uncertainty in decision-making

By analysing how do decision-makers cope with uncertainty, Lipshitz and Strauss (1997) defined three basic strategies to handle uncertainties in decision-making: (i) tactic of reduction, (ii) tactic of suppression, and (iii) tactic of acknowledgement (Table 2.2).

Table 2.2 – Strategies to handle uncertainty in decision-making according to Lipshitz and Strauss (1997)

| Category | Objective | Strategy |
|---|---|---|
| **Tactics of reduction** | The tactic attempts to retrieve information or to enhance predictability. | Collect additional information |
| | | Delay action |
| | | Solicit advice |
| | | Follow standard operating procedure |
| | | Assumption-based reasoning |
| **Tactics of suppression** | The tactic is assumed as a sort of denial of uncertainty. | Ignore uncertainty |
| | | Rely on intuition |
| | | Take a gamble |
| **Tactics of acknowledgement** | The tactic involves taking uncertainty into account in selecting a course of action, or preparing to avoid possible risks. This strategy can be applied when reducing uncertainty is either unfeasible or costly. | Preempting |
| | | Improve readiness |
| | | Avoid irreversible action |
| | | Weighting pros and cons |

A more recent approach was presented by Raadgever et al. (2011) under the context of environment management. These researchers defined several techniques divided into four groups (Table 2.3): (i) ignoring; (ii) knowledge generation; (iii) interaction; (iv) coping strategies.

Table 2.3 – Strategies to deal with uncertainty according to Raadgever et al. (2011)

| Category | Objective | Strategy |
|---|---|---|
| **Ignoring** | By not taking any action to measure uncertainty. | Ignoring uncertainty |
| **Knowledge generation** | It aims at assessing uncertainties, or at reducing epistemic uncertainties. | Uncertainty assessment |
| | | Reduction of epistemic uncertainty |
| | | Scenario study |
| **Interaction** | It aims at transferring knowledge about uncertainties from one group to another (communication), or uses techniques as dialogical learning, negotiation or oppositional models to reduce uncertainty (persuasive communication). | Communicating uncertainties |
| | | Persuasive communication |
| | | Dialogical learning |
| | | Negotiation |
| | | Oppositional modes of actions |
| **Coping strategies** | It acknowledges that some uncertainties cannot be reduced and instead aim at mitigating their negative consequences and/ to stimulate their positive consequences. | Preparing for the worst |
| | | Adopting robust solutions |
| | | Developing resilience |
| | | Adopting flexible solutions |

# CHAPTER 3. RISK ASSESSMENT PRACTICE AT RIJKSWATERSTAAT

## OVERVIEW ON THE PRACTICES OF RWS

### Asset management program

Every four years, RWS and the National Government define the Service Level Agreements (SLAs). The main objective of the SLAs is to guarantee that each network has a predetermined level of quality by taking into account existing risks within the network and a reference level of maintenance (van der Velde et al., 2013). The SLAs specify the performance levels that need to be delivered in each infrastructure type and define the national budget available for maintenance and operation activities (Figure 3.1).

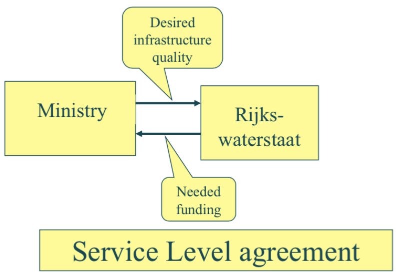



Figure 3.1 - Scheme of the SLA concept

To achieve these goals, RWS defined an asset management program to act as a framework to the decision-making processes within the organisation (Figure 3.2). The program is structured in three hierarchic levels – strategic, tactical and operational – and is supported by three main instruments:

(i) objectives and standards: instruments that set the quality required for the networks in terms of performance, condition and risk;

(ii) plans: instruments that plan each infrastructure level (network level, network branch level and object level), and

(iii) contracts: instruments that define the procurement procedures between the three parties involved - asset owner, asset manager and service providers.

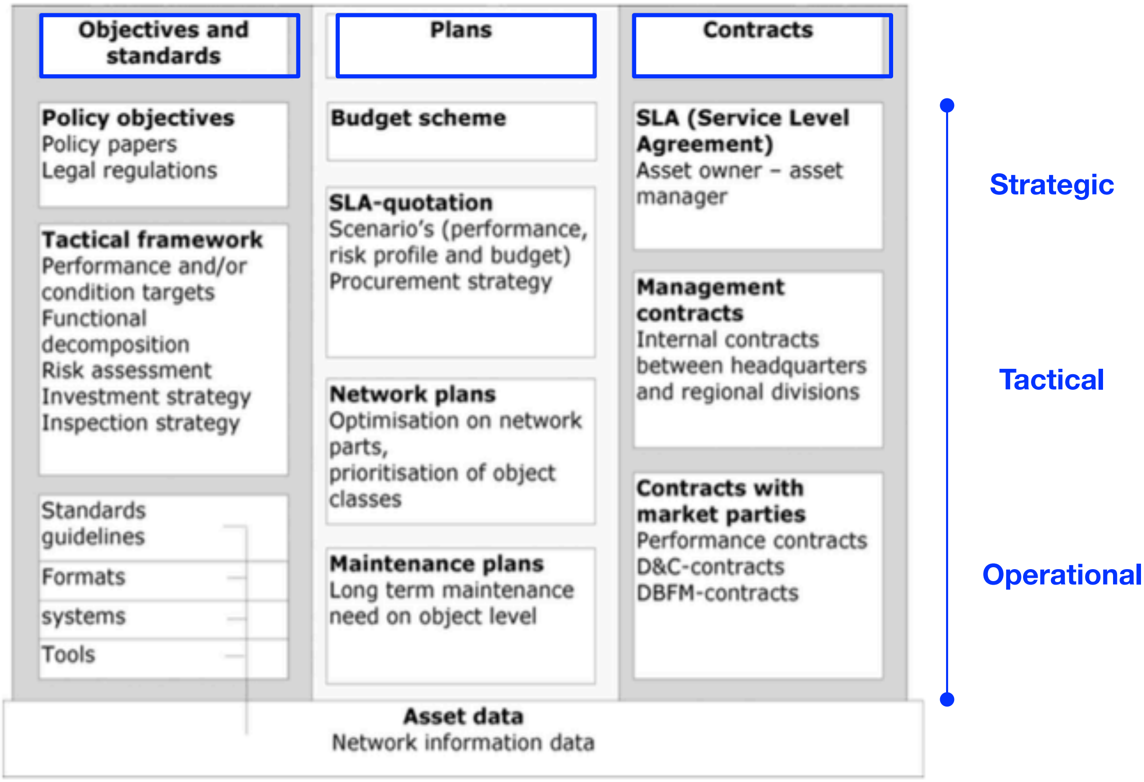



Figure 3.2 – Asset management program (adapted from van der Velde et al., 2013)

### Moving towards a risk-based approach

The translation of SLAs into specific requirements of a civil structure is a vital step to define a maintenance strategy. This translation is based on two main aspects:

(i) the functional requirements that the structure must meet, and

(ii) the functional failure definition that indicates when a structure is no longer acceptable.

For its turn, a failure definition is based on two main concepts (Figure 3.3):

a. network functions: defined according to the function of the structures and its parts;

b. network performance: translated into a maintenance concept and into generic performance requirements.

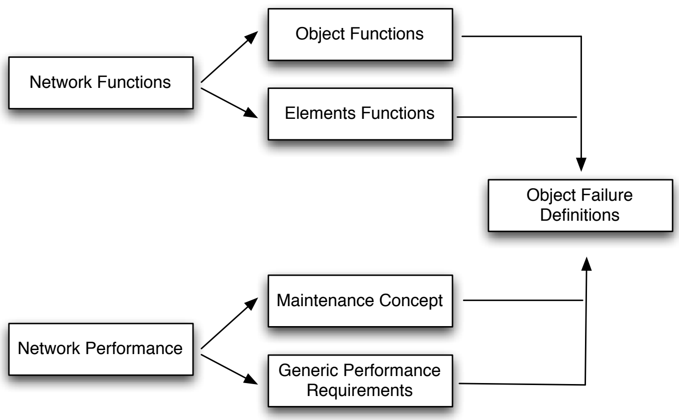



Figure 3.3 – Translation of SLAs into specific requirements: main concepts

By taking these aspects into account, RWS introduced a risk-based concept into its asset management program, which aims to accomplish three main objectives:

(i) to get information for managing the network;

(ii) to get an overview of costs and risks involved in order to provide insight into the agreed performance, on a short and long-term perspective; and

(iii) to organise and implement an efficient inspection program within RWS.

One important aspect of this risk-based concept is the definition and adoption of a risk-based inspection program, where the frequency and depth of periodic inspections vary according to a reference risk profile defined for each structure. The main purpose of such variation is to ensure that each inspection type act as a complement to each other despite their differences in function. These periodic inspections can be categorised in three groups:

(i) regular inspection: regular daily inspection (not focused);

(ii) condition inspection (every 2 years): targeted testing partly based on risk analysis for determining the current state and the current functioning of a structure and its elements; the feasibility of the maintenance plan of each structure is also assessed.

(iii) maintenance inspection (every 6 years): combination of desk analysis of risks and ‘in-situ’ inspection for updating risks and translate them into maintenance actions. The goal is to guarantee the long-term operation and performance of each structure.

### Maintenance management: critical decision-making processes

The inspection and maintenance activities performed by RWS are part of a lifecycle-based maintenance management process. This cyclical process occurs multiple times during the lifetime of a structure and is composed by six main maintenance (sub-)processes, as it is shown in Figure 3.4:


Figure 3.4 – Cyclic process maintenance plans for civil structures

Table 3.1 lists the parties responsible for each maintenance process.

Table 3.1 – Maintenance-related decision processes

| # | PROCESS | TASKS | RESPONSIBILITY |
|---|---|---|---|
| 1 | Decomposition and Maintenance Plan | - | Object designer and RWS (asset managers) |
| 2 | Inspection and Maintenance Advice | Programming inspection and maintenance analysis | Engineering firms (engineers and inspectors) |
| 3 | Adjustment of Maintenance Plans | | |
| 4 | Clustering and optimization | Network planning and maintenance programming process | RWS (programmers) |
| 5 | Maintenance execution | - | Service providers (contractors) |
| 6 | End of Service Life | - | RWS (asset managers) |

Data stored in DISK is vital to plan and program inspection and maintenance activities. Those activities have a vital role on the definition of the risk profile of each structure, on the definition and implementation of mitigating maintenance activities – and ultimately, on the costs of maintenance actions. Figure 3.5 shows the participants of these decision processes and matches them in relation to the flow of data to and from DISK. Each process is described below.

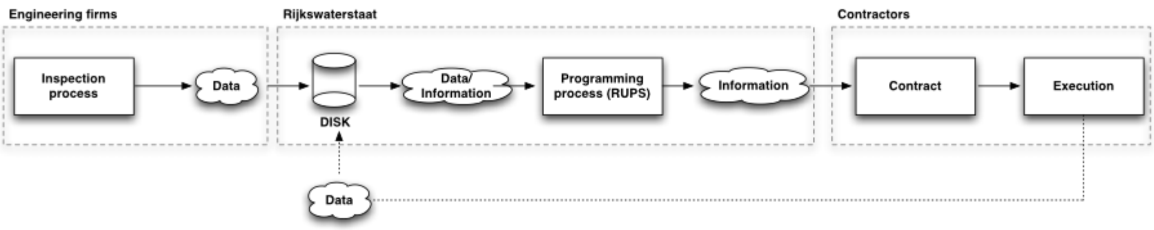



Figure 3.5 – Simplified process scheme addressing the parties responsible for each decision process

*Programming inspection and maintenance analysis*

Each civil structure has a maintenance plan that must be developed during its design phase. The plan is valid during the lifetime of the structure. It defines the inspection scheme advised for each structure and characterises the reference maintenance actions suggested for each structural unit (or element). The actions are also characterised with cost indicators and with implementation schedules.

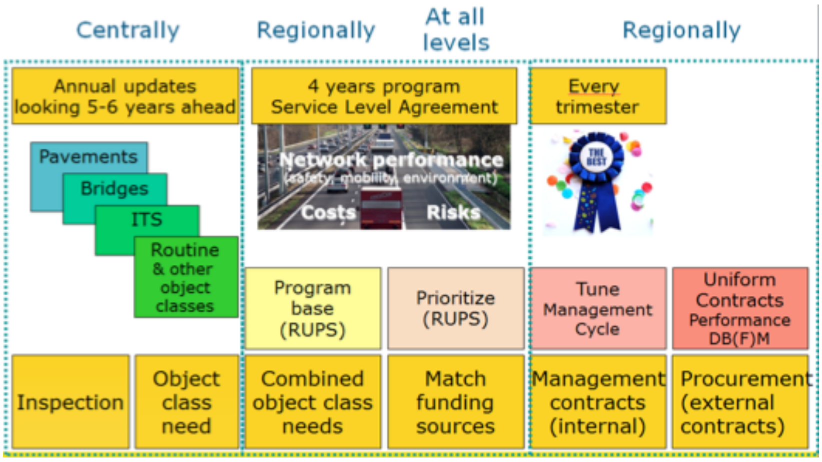



Figure 3.6 – Network planning and maintenance programming process

During the inspection, it is assessed the need for variable maintenance for a reference period based on a risk profile defined. Such maintenance actions are the input for the planning and programming process. The maintenance plan can be updated as a result of inspections.

*Network planning and maintenance programming process*

Based on the needs of different assets and tuned with other management systems, such as pavements or traffic management actions, all the maintenance actions are clustered and optimised in groups of objects (clusters) with the support of a specific planning tool: RWS Uniform Planning System (RUPS) (van der Velde et al., 2013). Such process is performed on a regular basis by each regional department of RWS: three times per year. It takes into account the budget available for maintenance actions and the network performance level defined in the SLAs. Figure 3.7 shows the scheme of this process flow.

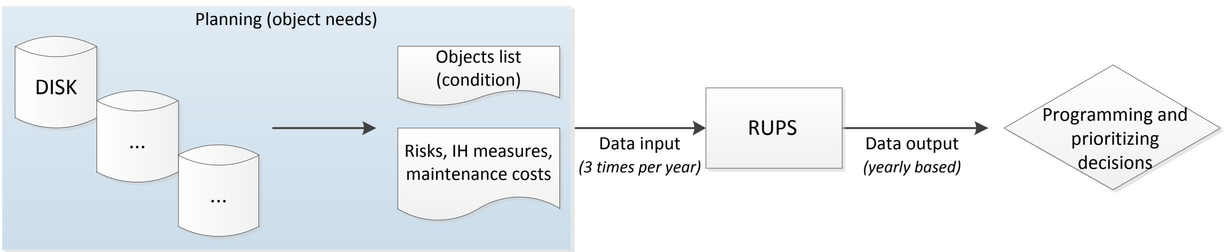



Figure 3.7 – Simplified scheme of network programming and prioritisation decision-process

## Risk assessment model

*Risk assessment concept*

Risks are assessed and treated according to the aspect that has more impact on the desired level of functioning as it is defined in the SLAs. This risk philosophy considers the following aspects. Firstly, the risk level is determined by the probability of its occurrence and its consequences. Secondly, the probability of occurrence is related to the time frame of the first two years after inspection. This includes the period between the identification of risk and the remedy diagnosis. A faster response is possible, but it has effect on other issues, as for example, on the availability of land, financial planning and maintenance programs. Thirdly, the probability of occurrence and the respective consequence determines the risk severity. The size of the risk is determined qualitatively on a scale that ranges from 1 (neglected) to 5 (unacceptable) (Table 3.2).

Table 3.2 – Matrix of risk analysis

| CHANCE | CONSEQUENCE | | | |
|---|---|---|---|---|
| | NEGLECT | SERIOUS | VERY SERIOUS | CATASTROPHIC |
| Chance of falling is unacceptable (calamity) | 3. Increased | 4. High | 5. Unacceptable | 5. Unacceptable |
| Chance of failing is very high | 3. Increased | 3. Increased | 4. High | 5. Unacceptable |
| Chance of failing is high | 2. Limited | 3. Increased | 3. Increased | 4. High |
| Higher than immediately after delivery the accepted probability of failure is approached | 1. Neglect | 2. Limited | 3. Increased | 3. Increased |
| Higher than immediately after delivery but within the acceptable probability of failure | 1. Neglect | 1. Neglect | 2. Limited | 2. Limited |
| Not higher than immediately after delivery | 1. Neglect | 1. Neglect | 1. Neglect | 1. Neglect |

*Risk assessment criteria*

The risk concept adopted by RWS is based on a set of reference criteria - the RAMS SHEEP aspects - which are the acronym for Reliability, Availability, Maintainability, Safety, Security, Health, Environment, Economic and Politics, respectively. Each criterion is defined as it follows:

- Reliability: the probability that the required function of the system can be carried out under the given conditions for a given time interval.
- Availability: the probability that the required function of the system can be carried out under the given circumstances during a given arbitrary time.
- Maintainability: the probability that the maintenance activities are possible within the specified time and under circumstances that the required function continues to run.
- Safety: related to the freedom from unacceptable risks in terms of injury to people.
- Security: related to the safety of a system regarding to vandalism and unreasonable human behaviour.
- Health: being related to physically, mentally and socially defined aspects.
- Environment: concerns the physical environment requirements.
- Economics: regarding the relationship between cost and value.
- Politics: concerning political-administrative and social requirements.

Currently not all of these requirements are related to the direct operation of a structure. Instead, they can be used for long-term risk analysis or for administrative issues. The next table details all the RAMSHEEP performance criteria, as they are currently used by RWS.

Table 3.3 – Definition of requirement aspects: RAMSSHEEP

| CRITERIA | PERFORMANCE CRITERIA | |
|---|---|---|
| Reliability | 1.1.R | Satisfy reliability requirements for moving parts and equipment |
| | 1.2.R | Meet structural requirements in relation to damages |
| | 1.3.R | Meet structural requirements in relation to revised standards |
| | 1.4.R | Meet structural requirements in relation to different use |
| | 1.5.R | Meet structural requirements in relation to defects in design, execution or management |
| Availability | 2.1.A | Meet object specific requirements with regard to the fulfilment of the object functions |
| | 2.2.A | Prevention of calamities |
| Maintainability | 3.1.M | Meet requirements relating to the maintainability of elements |
| Safety | 4.1.Sa | Meet object specific requirements with regard to the safe performance of the object functions |
| | 4.2.Sa | Prevent of calamities |
| Security | 5.1.Se | Meet the requirements with regard to the prevention of vandalism |
| | 5.2.Se | Meet the requirements relating to the protection of the object |
| Health | 6.1.H | Meet health and safety decisions |
| Surrounding and environment | 7.1.E | Meet design requirements |
| | 7.2.E | Meet environmental requirements |
| | 7.3.E | Comply with requirements relating to use/ comfort |
| Economics | 8.1.Ec | Moisture management in order |
| | 8.2.Ec | Prevent widespread or irreparable damage |
| Politic | 9.1.P | Meet requirements for image |

*Object condition*

During the inspection process the technical condition of each element of a structure is assessed. The status indicator of a structure is represented through a qualitative scale that ranges from 0 (good condition) to 6 (very poor condition) (Table 3.4). Such judgement is defined according to the deterioration level assessed by inspectors. To this end, inspectors are supported by standard references that can be both technical (e.g. the crack formation cannot be greater than a certain value) and/ or functional (e.g. the structure must meet a specified availability).

*Quality status*

The quality of a structure is a combined assessment of condition and risk. The quality represents the extent to which parts of the structure meet standards (condition) and its implications to meet performance requirements (risks). This assessment is automatically done in DISK since it sets the quality level equal to the lowest damage indicator of the respective element. To this end, the following matrix is used (Table 3.4):

Table 3.4 – Quality status indicator (condition *vs*. risk)

| CONDITION LEVEL | RISK LEVEL | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 0. In very good condition | 0 | 0 | 0 | 0 | 0 |
| 1. In good condition | 1 | 1 | 1 | 1 | 1 |
| 2. In good order | 2 | 2 | 2 | 2 | 2 |
| 3. In fair condition. Risk equipped regarding Reference Documents | 3 | 3 | 3 | 3 | 3 |
| 4. In poor condition. Does not meet Reference Documents | 3 | 3 | 4 | 4 | 4 |
| 5. In poor condition. Does not meet the minimum acceptable level | 3 | 3 | 5 | 5 | 5 |
| 6. In very poor condition. Disaster. Direct risk; do not meet any requirements | 3 | 3 | 6 | 6 | 6 |

NIS is a system supported by multiple individual data management systems. It contains information about all the physical assets managed by RWS. The information stored in NIS is organised in three main categories:

(i) quantity: what, where and how,

(ii) quality: condition, and

(iii) performance use: traffic intensities or water drainage.

The information collected in each individual system is organised in products that RWS uses internally to support multiple decisions, such as:

- to monitor the SLA's;
- to control and monitor performance indicators (per network type and per regional service);
- to collect area data (wet and dry), which is the basis to determine the budget provision;
- to define area dashboards for asset management;
- to forecast area growth in order to define the national budget;
- to support the definition of contracts for network management.

As an example, Figure 3.8 shows the information production line from DISK to NIS.

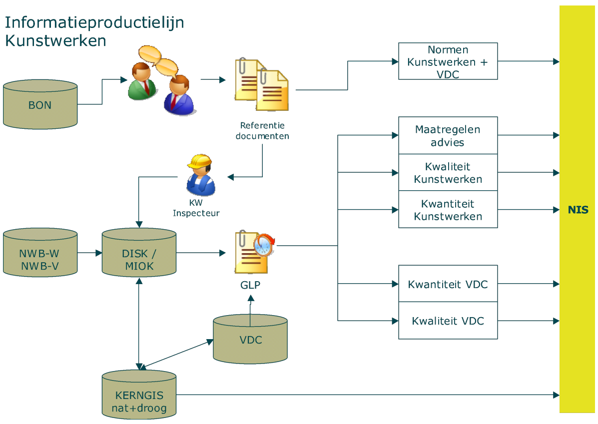



Figure 3.8 – Information production line from DISK to NIS

DISK is a customised and single-user system that stores all the relevant technical and administrative data related to civil structures. The data collected and stored in DISK is categorised according to three main groups (Figure 3.9): (i) inventory data, (ii) inspection data and (iii) intervention data. Appendix 1 presents a detailed description of the data collected and stored in DISK.

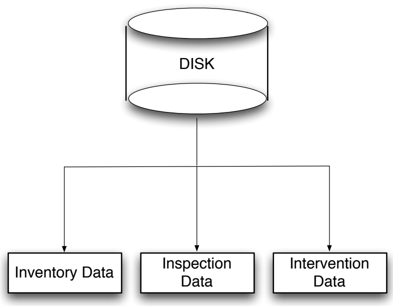



Figure 3.9 – DISK data categories

# Inventory data

Inventory data characterises the civil structures according to administrative and technical issues, geographic location and reporting aspects. This data is created during early design phases and rarely changes during the lifetime of a structure.

# Inspection data

Inspection data is collected on a six-year basis for each civil structure. It includes the risks and conditions assessed and the status indicator of the object.

# Intervention data

Intervention data is related to maintenance actions prescribed by inspectors as a result of inspection activities. It includes details about the maintenance action, the costs and the implementation scheme suggested. While data created during registration rarely changes during an object lifetime, data collected and generated during inspection and maintenance activities is variable during the lifetime of a structure.

The processes 1,2 and 3 (Figure 3.10, under the green area) are object specific. Data generated or collected through these processes is related to a single structure. The processes 4, 5 and 6 (Figure 3.10, under the red area) are more network-related; the data generated through these processes is provided by external systems. These processes contribute little to update or generate new data in DISK; however, they make use of data stored in DISK to support other processes.

The Maintenance Execution process (Figure 3.10, under number 5) is supported by external systems and has a connection with process 3 (object Maintenance Plan). This is because the plan makes reference to standardised maintenance actions. When the object reaches the end of its lifetime, its status is updated in DISK and new data is generated.

Another DISK data source is the set of internal instruments: the Reference Documents (also known as BON/ RBO). These documents are produced by RWS to translate the performance indicators established in the SLAs. They include the area managed by RWS and a description of the processes to be maintained by taking into account national regulations. In addition, they provide standard data related to management actions per object type. Reference Documents also include the definition of object functional requirements, give an outline of object maintenance strategies and provide reference maintenance advice to inspection activities, including data object maintenance intervals and unit costs. They include standard ageing behaviour for civil structures (deterioration process) and object technical standards. These documents are updated on a yearly basis.

Part of these standard data is transferred to DISK on a regular yearly basis and is used to support DISK data users. Typically, they support inspection and maintenance actions.

KERNIS is another DISK data source and establishes a connection between an object and its geographic location. The definition of this geographic reference occurs during the design phase and rarely changes during the lifetime of the structure.

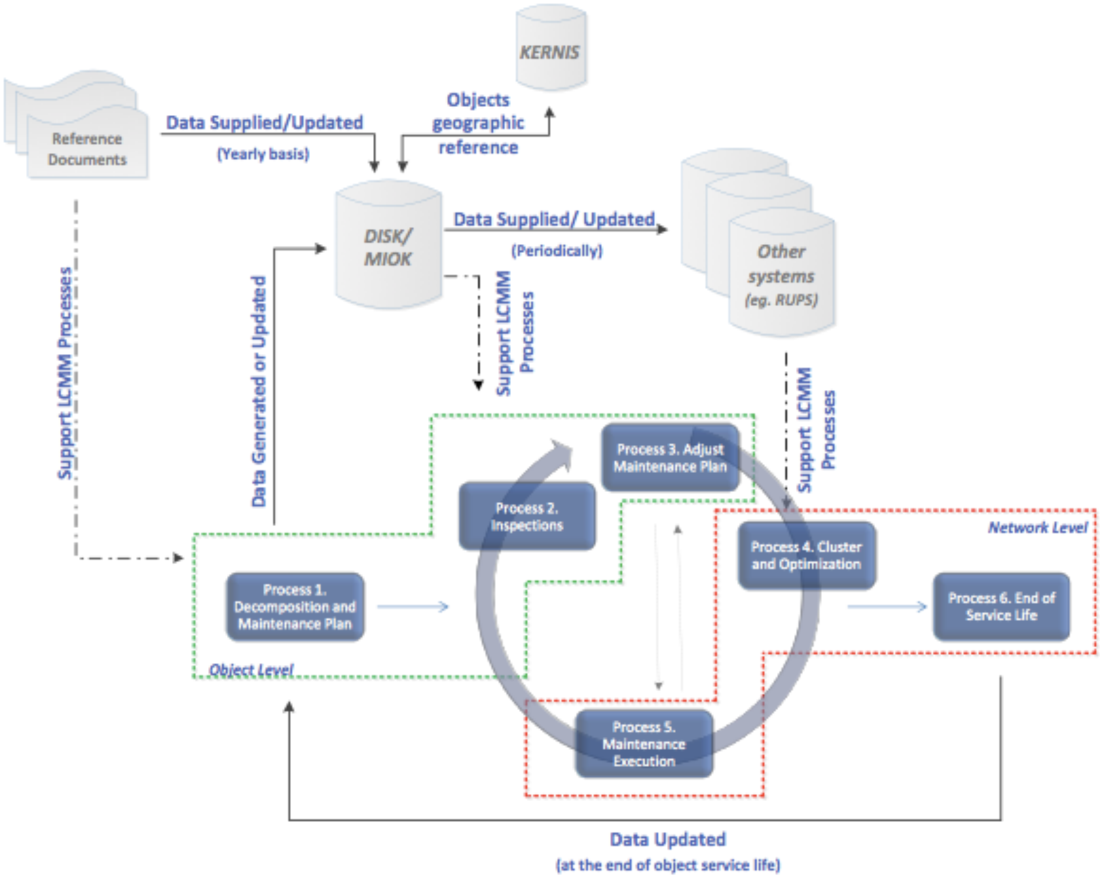



Figure 3.10 – Flow of data to and from DISK

## NARROWING DOWN THE PROBLEM SCOPE

The maintenance management program implemented in RWS is composed by several processes and involves a large number participants (Figure 3.11). Such practitioners taking part in the program have the perception that some challenges are affecting its efficiency and effectiveness.

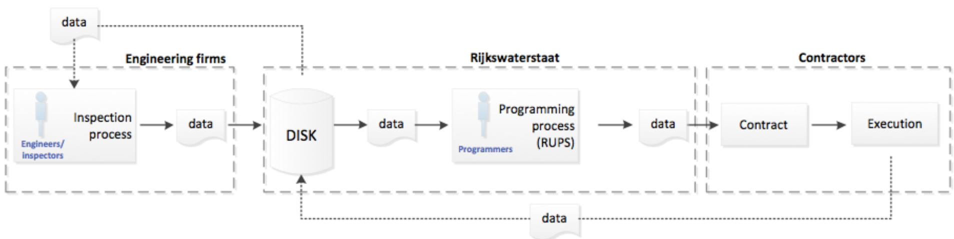



Figure 3.11 – Simplified process scheme addressing the respondents to the respective process

Based on the interview results, which protocol is presented in Appendix 2, we identified a set challenges by grouping the practitioners' perceptions into five main categories (Table 3.5). To this end, we took into account the process that the challenges are related to. Appendix 3 includes a report with the detailed explanation of the challenges identified during the interviewing process.

Table 3.5 – Resume of the challenges perceived by practitioners and the respective process

| CHALLENGES PERCEIVED | PROCESS IN THE MAINTENANCE MANAGEMENT PROGRAM |
|---|---|
| Limited usefulness of data management system to support the inspection process | Inspection and maintenance analysis |
| Limited usefulness of the data management system to support the programming process | Network maintenance programming |
| Problems with communication between maintenance management program | All the processes |
| Problem with the implementation of the inspection model | Inspection program and inspections model |
| Perceived technical limitations of DISK and underused capabilities | All the processes |

## ANALYSIS OF EXISTING RISK RELATED CHALLENGES

The interviews with representative data users provided a set of perceived symptoms about the limitations of the current DISK data system in the support of a risk-based maintenance program. Considering the importance of the risk-based approach adopted by RWS, we focused on the perceived challenges related to risk and group them in three categories.

### (1) Ambiguous and subjective risk criteria during risk-based assessments

Data collected and produced during a risk-based inspection is vital not only to define the current risk profiles of objects and the respective mitigating maintenance actions, but also to support future inspection processes. This data is frequently sent to network planning and programming processes, where all the network's maintenance needs are combined. Therefore, this data is also vital to the current and future effectiveness of this process. However, practitioners perceive the current risk criteria – and ultimately, the risk assessment itself - as ambiguous and subjective. Two main reasons are pointed as the causes for such perception.

Firstly, practitioners claim that the qualitative nature of the RAMSSHEEP criteria used for risk assessment leads to different interpretations between practitioners involved in maintenance-related decision-making processes.

Secondly, practitioners consider that such lack of understanding is intensified by the absence of mechanisms that support risk assessment, affecting all the activities of inspection and maintenance programming.

As a result of these symptoms, the risk data stored in DISK may be affected and may as well have an impact on succeeding decision processes, as the maintenance programming. The practitioners of this process share the inspection's perceptions by claiming that besides not understanding the RAMSSHEEP risk criteria, the reasoning behind the risk data that they have assessed is lost. This is because, the risk data that arrives to the maintenance programming process is provided as a number and not as a clear reasoning manner. Thus, it is perceived as a critical gap for decision-makers.

Such lack of operationalisation of the RAMSSHEEP risk criteria not only creates barriers to data interpretation and data reliance, but also leads to subjective assumptions during the maintenance programming processes. As an outcome of such assumptions, an optimal maintenance planning and programming may be compromised.

### (2) Inconsistency of risk-based approaches between decision processes

The maintenance-related decision processes of civil objects are data dependent. As a matter of fact, each decision-process is supported by data collected or produced on multiple decision-making processes. Such data collection or production must be in line with specific management guidelines that individually regulate each of those processes.

However, those guidelines seem to affect the properties of data collected and produced in each decision process. This is particularly relevant for those decision processes that are not risk-based focused. For example, data collected under a risk-based inspection has different attributes than data collected under a condition inspection, which focuses exclusively on damage and not on risk or criticality. As a result, the lack of consistency between data from different decision processes raises the perception that some data has limited usefulness. This perception creates aversion to the use of data that may be critical to the decision-making.

### (3) Updating risk level data between and in risk-based processes

Data collected and produced in each process is used along the different maintenance-related processes (i.e. from inspection to maintenance execution). Thus, the data dependency between those processes makes them vulnerable on the efficiency and effectiveness of data transferring and communication.

However, practitioners claim that the configuration of data flow can affect such data interfacing. This is particularly relevant for the timely accuracy of an object's risk profile. Such perception is based on the fact that the risk profile is likely to change during the maintenance processes due to its dependency on time and on maintenance decisions.

As a result, the lack of data updating seem to raises concerns on the timely accuracy of data stored and used for maintenance-related decisions.

## DISCUSSION

The challenges identified raise two main points for reflection:

### (1) Fuzzy understanding and relationship of risk criteria

The RAMSSHEEP risk criteria seem to be at the origin of the first challenge identified. Two main points of concern deserve discussion.

Firstly, the risk criteria used to perform the risk-based inspection and the maintenance programming seem to not be completely clear to all the practitioners involved in those processes. As highlighted by the practitioners, the RAMSSHEEP criteria are defined on qualitative terms, which raise difficulties about the meaning of each criterion. Questions about the "what does the concept of Availability mean?" or "what is Safety?" arise frequently among practitioners. Such lack of understanding has consequences on the risk assessments and on the respective risk profiles, since the risk estimation lacks a structured approach to support the definition of the risk criteria and level involved. One of the possible consequences of such lack of understanding is the variability in the reasoning used between inspectors and programmers. For example, based on the same input data regarding similar damage mechanisms, different inspectors can arrive to considerably distinct object's risk profiles. Consequently, the maintenance programming may also be affected. During the programming process, a weak understanding of the risk criteria leads to subjective reasoning and assumptions among practitioners.

Secondly, the lack of understanding of risk criteria is intensified by the complex relationship between them. In a study about maintenance decision support models for railway infrastructure, Patra (2007) discussed the relationship between each RAMS parameter. The researcher concluded that each parameter is affected by system conditions (i.e. source of failures introduced internally), by operating conditions (i.e. source of failures that result from the operating conditions) and by maintenance conditions (i.e. source of failures caused by maintenance actions). These sources of failures do not only depend on the reliability of the system (i.e. internal and external failures of the system), but also on the interaction between failures. Such complex relationship between criteria can be intensified since objects can be concurrently affected by multiple hazards, such as traffic loading, flooding and earthquakes. As a result, the occurrence of one or more hazards may lead to failures with consequences on multiple criteria. For example, a bridge structural failure (i.e. reliability) may compromise the safety criteria of the bridge (e.g. by increasing the human casualties), may have an economic impact on the region (e.g. by blocking the access to a vital industrial area) and may bring political consequences for the transportation agency (e.g. by jeopardising the agency's reputation). This example shows that a single failure on the technical domain (i.e. related to the RAMS aspects) may lead to several consequences on the health, environmental and economic-political domain (i.e. related to the SHEEP criteria).

These challenges raise doubts to practitioners involved in the maintenance-related processes regarding the nature and the level of the risk involved. As a result, practitioners are vulnerable to heuristics and subjective judgments, which may compromise the efficiency and effectiveness of risk-based decisions.

#### (2) Challenges with data collected, communicated and used between and in processes

The data collected and used between and in decision processes seem to be at the origin of the challenges identified, which deserve further discussion.

Firstly, the incomplete implementation of risk-based approaches within the maintenance-related decision processes leads to incompatibilities between those processes. As a result, data generated in each process have distinct properties (or characteristics). The example provided by practitioners is a faithful illustration of this challenge. Data collected under a risk-based inspection has different attributes than data collected under a condition inspection, which focuses exclusively on damage and not on risk or criticality. Such differences may provide conflicts in the interface between databases – and ultimately, between decisions processes that make use of both data sources.

This challenge leads us to reflect on another aspect. The output of any inspection process is not only on the data domain; instead, as a result of an inspection process, part of the data generated is assembled into a meaningful logic and is stored in the database with a character of information. To some extent, part of this information needs to be brought back to data in order to feed the following decision process. As a result of this translation, some vital input seems to be lost, as practitioners perceive it. For example, inspectors use a certain reasoning to determine the risk profile, which is not delivered to the programmers; instead, programmer receive the data about object's risk profile in a numerical way, which meaning is difficult to understand. This means that the interfaces between processes have an impact on the way information is drawn from the data and vice-versa.

Furthermore, to intensify this challenge, each decision process uses its own model as a decision support, which means that each decision is directly linked to the process. If data stored in the database – the linking element – is not updated continuously between each decision, it leads the decision-makers to base their decisions on timely inaccurate data.

Data accuracy is a necessary but not sufficient condition to support decision-making. Besides being timely accurate, data also needs to be adequate to the decision process. However, based on the current risk criteria – RAMSSHEEP - the data collected in each decision process seems to be insufficient to perform a risk-based assessment and analysis.Despite being characterising by object's inventory, inspection results and object maintenance planning, the existing database (DISK) lacks data that allows inspectors to perform an effective assessment of the risks involved in the health, environmental and economic-political domain. Using the same example as above, if a vital bridge of a network has a certain reliability risk, it is likely that the functional failure of a bridge will have consequences on the economic and political domain. Thus, the risk on the economic criteria is difficult to assess based on the available data in DISK.

The incompatibilities between data properties, the timely inaccuracy of data stored and the unavailability of vital data to support the maintenance-related decision processes make practitioners vulnerable to heuristics and subjective judgments with the aforementioned effects on the efficiency and effectiveness of risk-based decisions.

## SELECTION OF POTENTIAL FOR IMPROVEMENT

From the challenges perceived by practitioners, it is visible that the existing program has room for improvement. In fact, each process has a stake in the inspection and maintenance program, which means that decisions and the respective data that are derived from early decisions will affect the subsequent processes.

It is our purpose to design an intervention that minimises the symptoms perceived. However, due to time limitations, we narrowed down our focus to the symptoms perceived inside RWS (i.e. to the processes performed in and by RWS). Thus, our design focused on the symptom of limited usefulness of the data management system to support a risk-based maintenance programming process. Figure 3.12 shows the intervention area of the risk-based model.

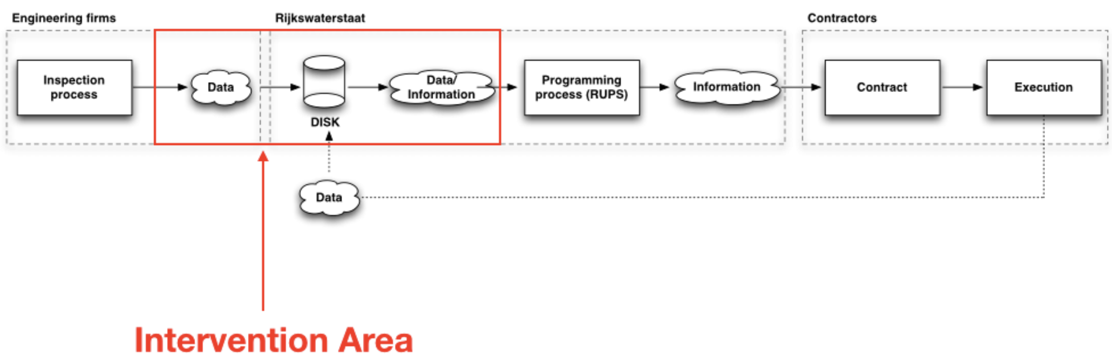



Figure 3.12 – Intervention area of the risk-based model

To solve the related symptoms, we proposed the development of a risk-based model that provides support to programmers to better deal with the risks assessed during inspections by making use of the RAMS criteria. Such model aims not only to support the translation of the *right* data from DISK to RUPS, but also to enhance the understanding about the risk criteria (RAMS) underlying a risk-based maintenance program. While the direct contribution of the proposed model is to improve the way inspection data is translated to the programming process in a risk-oriented manner, the indirect benefits are:

- to raise awareness on the practitioners involved in maintenance-related decisions about the need to move towards risk-based inspection and maintenance approaches;

- to define reliable maintenance projects as a result of maintenance programming processes;

- and ultimately, to provide foundations to improve the efficiency of the overall life-cycle management of individual civil structures.

## DESIGN SPECIFICATIONS

Based on the input of the interviews, we acknowledged a set of design specifications to be addressed to the design model (Tables 3.6 and 3.7).

Table 3.6 – Design specifications I

<table>
<tr><th>#</th><th>REQUIREMENT</th><th>MOTIVATION</th></tr>
<tr><td>1</td><td>Definition of a model to support managers to understand the RAMS criteria involved in the risk assessment of civil structures and the relationship between the set of them.</td><td>“We need a tool that helps managers to better understand that method [RAMSHEEP].”<br>“I think inspection processes are very subjective, also the actions are subjective and also the programming is very subjective; and also does the RAMSHEEP, which is also very subjective; (…) this affects data properties, (…) data depends on inspectors who have made the inspections. So, the quality is various: it depends on the experience of the inspector. This will affect the quality of data.”<br>“I would like to see a change. What is important for a good description of what means a 2, a 3 or a 5 for the all inspection process?”</td></tr>
<tr><td>2</td><td>The model must support maintenance programmers to define the risk profile of a structure and to rank such risks in relative levels.</td><td>“Programmers just remember the risk number; they are missing things that they can’t find; [the problem is] not presenting the right information that is actually there. If they want to do programming they are missing things that are actually there but they can’t find. For example, which risk is involved? These sorts of data are in DISK but they are not exported to DISK in such a way that is easy to understand or find.”<br>“I think data should be more related to performance of the network or more related to risks; (…) risks are in data, but which risks are more important, it is not done yet; (…) we would like to have the risk result, when we got the measure (…) we need the characteristic of the measure in the programming, especially the risk [because it] is missing; (…); risks are in the data, but they are not assessed which one is the most important in an hierarchy of risks; (…).”</td></tr>
<tr><td>3</td><td>The model must include element and object level.</td><td rowspan="2">“The risk classification is done separately for each elements and not for the all structure: you look at the elementss, but you don’t look at the all structure; (…) the risk doesn’t say anything about the importance of the different actions together; sometimes a category 3 in the deck is more important than a category 4 in the balustrade.”</td></tr>
<tr><td>4</td><td>The relationship between elements must be clear.</td></tr>
</table>

Table 3.7 – Design specifications I (cont.)

<table>
<tr><th>#</th><th>REQUIREMENT</th><th>MOTIVATION</th></tr>
<tr><td>5</td><td>The data/ information generated during the usage of the model should be stored in the current data management system as a support to further inspections and maintenance processes.</td><td rowspan="2">“This should be made in the DISK system itself (…) because the all analysis of what we are doing now, is not even part of DISK. If that is going to be in DISK, I think it is a better system. It is still easy to work with and the quality becomes good for the inspectors that need to work with it, because the quality now is not as good as it could be, because you have to wait most of the time, and not everything is intuitive to work with; so, if you could make it a bit better for everyone, so for everyone, easier to work with, and also nice to work with – so, the quality of the report would be better. Actually, DISK should be able to store more of the results that are part of the analysis process, the inspection process and the process that is going on in the brain of the consultant: more than what is currently able to do.”</td></tr>
<tr><td>6</td><td>All the subjects involved in the processes of inspection and maintenance programming should be able to understand and interact with the model.</td></tr>
</table>

The general approach used in this project was based on the idea of the full involvement of the owner in every step of the designing process. Such involvement resulted in an additional set of requirements (Table 3.8).

Table 3.8 – Design specifications II

| # | REQUIREMENT |
|---|---|
| 7 | The model procedures must be compatible with the current inspection model and with the current maintenance programming process. |
| 8 | The model must give the programmers a clear indication not only of the condition of each asset, but also about the level of its structural capacity. |
| 9 | The model outcomes should be valid for a reference period ahead of the inspection time. |
| 10 | The model should incorporate the possibility to be extended to a network level of analysis. |

# CHAPTER 4. RISK ASSESSMENT METHODOLOGY BASED ON RAMS CRITERIA

## DESIGN CONCEPT

The main objective of this study was to develop a risk-based assessment methodology. The underlying idea of this model is that it can enable a systematic determination of present and future needs for maintenance, rehabilitation, or eventually, replacement of civil structures or their elements. Such tool is particularly relevant for maintenance programmers, since they are responsible for translating the maintenance plans defined during inspections into feasible operational maintenance projects.

The design model is fully based on the concept of current and multi-level risk assessment, where a system of inspections work as an input to revise the risks involved in each civil structure and its elements. Another aspect of the model is that these inspections are used to make line progressions over a reference period, which in this case was assumed 10 years. By better understanding the potential risks involved during a certain time period, maintenance programmers have means to plan and prioritise maintenance actions in a risk-oriented manner, with the goal to keep risks below a certain threshold.

Risks are assessed with support of RAMS aspects and their mutual relationship, with reliability acting as a key criterion during the assessment. From the structural perspective, the model can be seen as a set of blocks, each designed for a specific and operative task. Each block consists of a procedure package with operational tools that can be used by analysts responsible for the assessment (i.e. inspectors and programmers). Analysts can make use of (semi or fully) probabilistic-based approaches. Independently of the approach used, the choices must be justified and registered for further assessments in time.

## ROADMAP OF THE RISK ASSESSMENT MODEL

The model is grounded on performance-specific data, where the outcomes of specific blocks are needed as an input to the subsequent blocks. The design model is structured in three dependent parts - (0) structure (or system) characterisation, (1) element-level and (2) structure (or system) level (Figure 4.1).


Figure 4.1 – Blocks that compose the risk assessment model

After the characterisation of the criticality of each civil structure (part 0), part I aims at defining the reliability risk profile for each of its units (or elements). This risk profile acts as a reference to select a set of alternative maintenance actions that can be implemented on a specified time and (if necessary) frequency, in order to upgrade the current functional and structural performance levels to a satisfactory, or more desirable, level. Then, each maintenance action is analysed in terms of its impacts on risk performance of each RAMS criteria: reliability, maintainability, safety and availability. The result of the first part is a structured risk picture of possible maintenance actions to be applied on each element over a reference period.

Understanding the risks involved in each element is vital to strategically select a group of possible maintenance actions based on risk performance. However, the risk behaviour of an entire structure is not necessarily proportional to the risk behaviour of its individual elements. Thus, the second part of the model aims at defining a set of maintenance strategies for the civil structure, seen as a system. These strategies are based on a group of maintenance actions defined in the first part and on the respective risk profiles of each RAMS criteria.

When a group of strategies is defined, the availability risk profile on the structure level must be assessed. For its turn, the reliability risk profile on the element level might change from the initial assessment due to its time-dependent nature. As a result, the re-evaluation of the risk profiles on the element level is needed. The model ends with the selection of a strategy that satisfies the risks performance limits initially defined by RWS. The basic parts of the model and the schematic process flow are illustrated in Figure 4.2. The complete risk-based model is presented in Appendix 4. The detailed content of each block of the model is explained in the following sections.

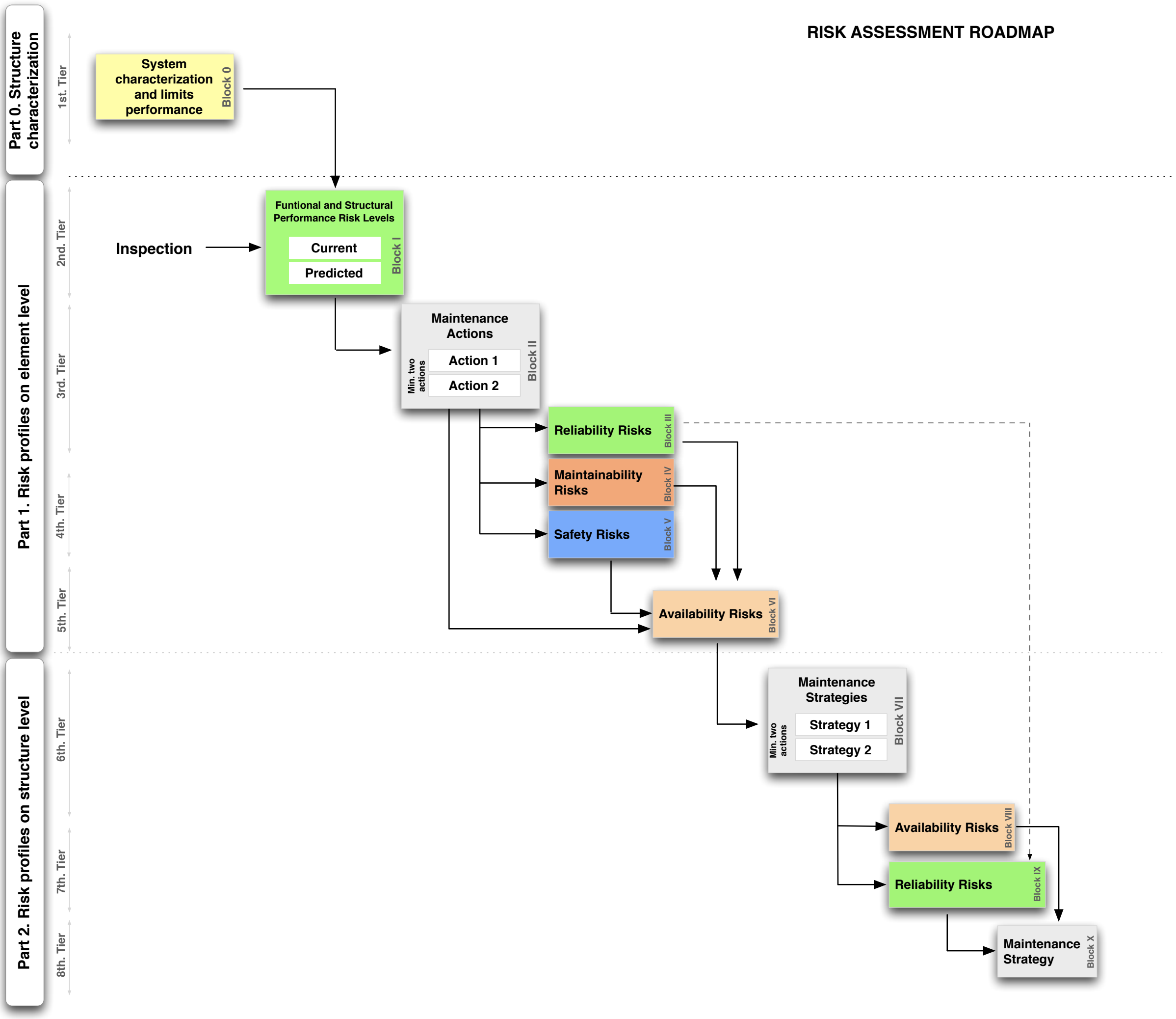



Figure 4.2 – Risk assessment roadmap

## DATA ROLE: INPUT/ OUTPUT

Data is a vital part of the model since it provides foundations to the predefined assessments. In fact, the quality of data available determines the confidence level adopted for those assessments: the more precise the data available is, the more reliable the assessments are. In a reliability-based assessment, for example, such confidence level can determine the upper and lower bound of the theoretical performance curve. The data needed to feed the model is categorised in two groups: general (i.e. common data to all the blocks) and specific (i.e. precise data to each block). Based on this division, we identified the following types of data needed to perform a reliable risk-based assessment:

- *Inventory data*: includes all the information related to bridge identification, geographical location and features, administrative issues, construction and previous retrofits.
- *Design data*: model of the civil structure, representing in a detailed manner the logical distribution of its elementary units and data on material properties. The categories below are also part of design data:
    - *Design assumptions:* description of the assumptions used during the structure design, namely design loading and specifications; ideally, it includes indications about possible reduction of safety level reflecting a paradigm change from previous binding codes to the current ones.
    - *Loading history:* historical traffic data (i.e. current traffic load and prediction of traffic progression).
    - *Load modelling:* original static calculations (structural design) supported by loading structural models.
    - *Time-variant reliability models:* reliability-based data concerning the capacity of the bridge and the set of reliability indexes, each associated with an ultimate limit state and a specific structural unit or substructure.
    - *Climate/environmental features*: characterisation of environmental conditions and attributes (external do the structure); usually, they include chemical exposure, climate of the area, location of the structure and surroundings of the foundation.

- *Inspection history*: detailed characterisation of all the inspection activities performed on the structure; usually, this results in a form of report with all the judgments and ratings from inspections, as for example:
    - *Condition state data*: it includes the identification and characterisation of existing deterioration processes, and if so, the evaluation of the degree of deterioration, with respect to the structure in its original condition. Typically, this data is qualitative and includes, for example, a plain description of the damage, namely type and extension, possibly supported with pictures and test results.
    - *Material tests*: results from non-destructive tests performed on laboratory or *in-situ*, during the inspections. Examples are: chloride intrusion/compressive strength or carbonation tests.
    - *Dynamic measurements*: related to dynamic measurements from structural health monitoring. Examples are: measurement of structural parameters (joints displacements, bearings displacement, vertical displacement, rotation or strain); measurement of dynamic parameters (acceleration); measurement of durability parameters (corrosion); measurement of scour parameters (scour) or measurement of environmental parameters (temperature and relative humidity).
- *Maintenance history*: characterisation of all the maintenance and/ or rehabilitation actions implemented on the structure.
- *Maintenance plan (IHP):* document developed during the design phase of each structure containing the inspection scheme to adopt during the structure's lifetime; it characterises reference condition and risks profiles determined agains specific performance indicators and provides reference maintenance actions advised to the structure and its elements. The plan is usually updated as a result of the inspection actions.
- *Internal reference documents*: are instruments that indicate strategic package of actions to manage and to maintain infrastructure objects in a long-term perspective; it includes references to: the networks under management, the maintenance strategies and to the methods used in those strategies in compliance with laws, regulations and current policy. Usually, this document is used as a reference for budget preparation, annual planning and internal management debates.

## PART 0. STRUCTURE CHARACTERISATION AND LIMITS OF PERFORMANCE

The goal of Part 0 is to characterise the civil structure under analysis in terms of criticality (Block 0.1) and to define the functional and structural performance limits accepted by RWS (Block 0.2). As it was explained during Chapter 2, functional performance is related to the designed function of the object (i.e. what is the object expected to do), while structural performance is related to the structural safety of an object (i.e. capability to deliver its designing function).

### Structure characterisation (Block 0.1)

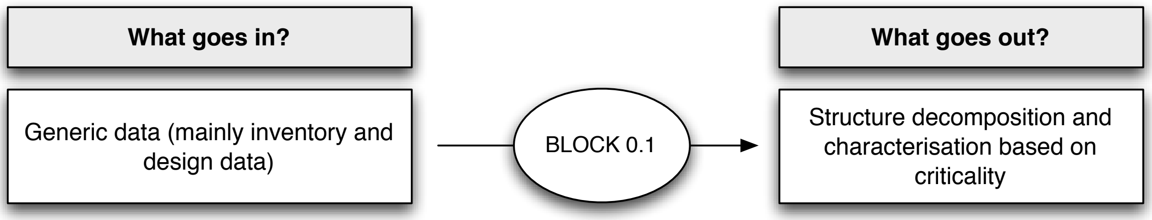



Figure 4.3 – Block 0.1: Schematic input and output of the block

This block aims to provide a solid understanding of the system, particularly in terms of functional and structural behaviour, before the actual risk assessment. Each structure must be decomposed into structural units or elements based on its functionality. Ideally, these units must be characterised with a functional description (i.e. what is the element expected to do). For example, the function of a sound barrier is to absorb sound. Then, each unit must be weighted with a utility function in order to provide a rational basis for understanding the relative effect of each element on the system. Typically, this involves the identification of the elements or units that are critical to the functional integrity of the structure, also known as criticality.

Literature related to Structure Performance Indicators shows that there is no standardised way to perform such structural analysis. Yet the structural characterisation can be done with different levels of complexity. For example, a simple criticality map might be adopted, where significant rates of each structural unit are multiplied by weighting factors defined according the type of material. An example is provided on Table 4.1.

Table 4.1 – Example of structural characterisation based on element criticality as a function of material

| STRUCTURAL GROUP | | | MATERIAL DESCRIPTION | | | | |
|---|---|---|---|---|---|---|---|
| | | | STEEL | PRECAST CONCRETE | CAST-IN SITU CONCRETE | TIMBER | OTHER |
| Weighting factors | | | 1.0 | 2.0 | 3.0 | 4.0 | 1.5 |
| units | Superstructure | 3.0 | 3.0 | 6.0 | 9.0 | 12.0 | 4.5 |
| | Substructure | 3.0 | 3.0 | 6.0 | 9.0 | 12.0 | 4.5 |
| | Deck joints | 1.5 | 1.5 | 3.0 | 4.5 | 6.0 | 2.25 |
| | Bearings | 1.5 | 1.5 | 3.0 | 4.5 | 6.0 | 2.25 |
| | Miscellaneous | 2.0 | 2.0 | 4.0 | 6.0 | 8.0 | 3.0 |
| | Culverts | 1.0 | 1.0 | 2.0 | 3.0 | 4.0 | 1.5 |

Another possibility is to perform a more complete criticality analysis through the use of FMECA tools (Failure Modes and Effect Criticality Analysis), FTA (Fault Tree Analysis) or ETA (Event Tree Analysis), where possible failures of the system can be identified since early design phases and updated during its lifetime. These sort of techniques also allow for considering design characteristics that are critical to the structural behaviour of the system, such as redundancy or vulnerability. One of the limitations of allocating utility functions is precisely the lack of relation to an absolute measure. Thus, independently of the method adopted within the organisation, the weighted scoring system must be calibrated before its implementation with support of literature and structural engineering experts.

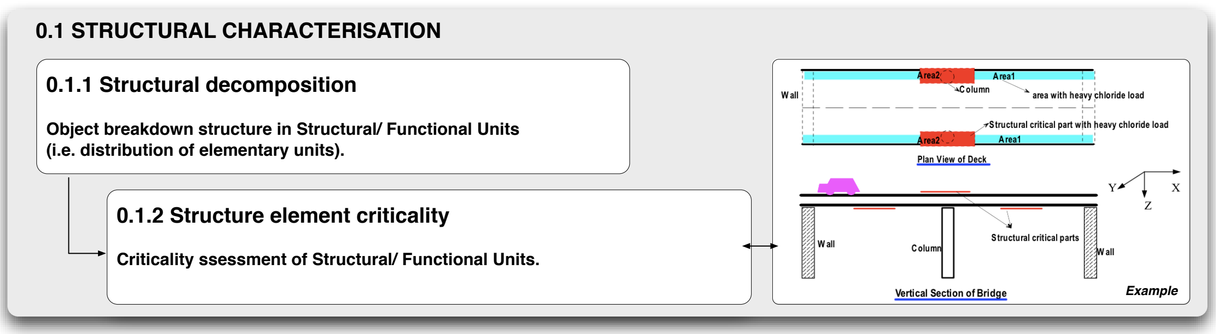



Figure 4.4 – Block 0.1: Structural characterisation (extracted from the model)

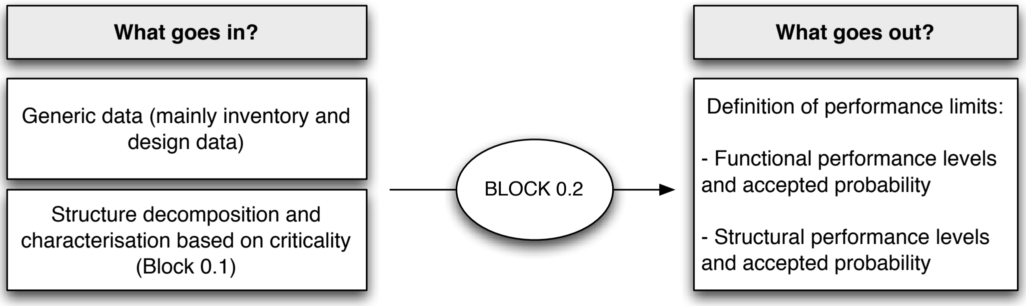



Figure 4.5 – Block 0.2: Schematic input and output of the block

Following the characterisation of the structure's criticality, RWS must define the accepted limits of functional and structural performance. These limits indicate the extent of criticality (or acceptability) for the functional and structural performance assessed during the inspection process; they separate a desired from an adverse level of performance on a grading scale that varies between 0 (very good) to 6 (very poor).

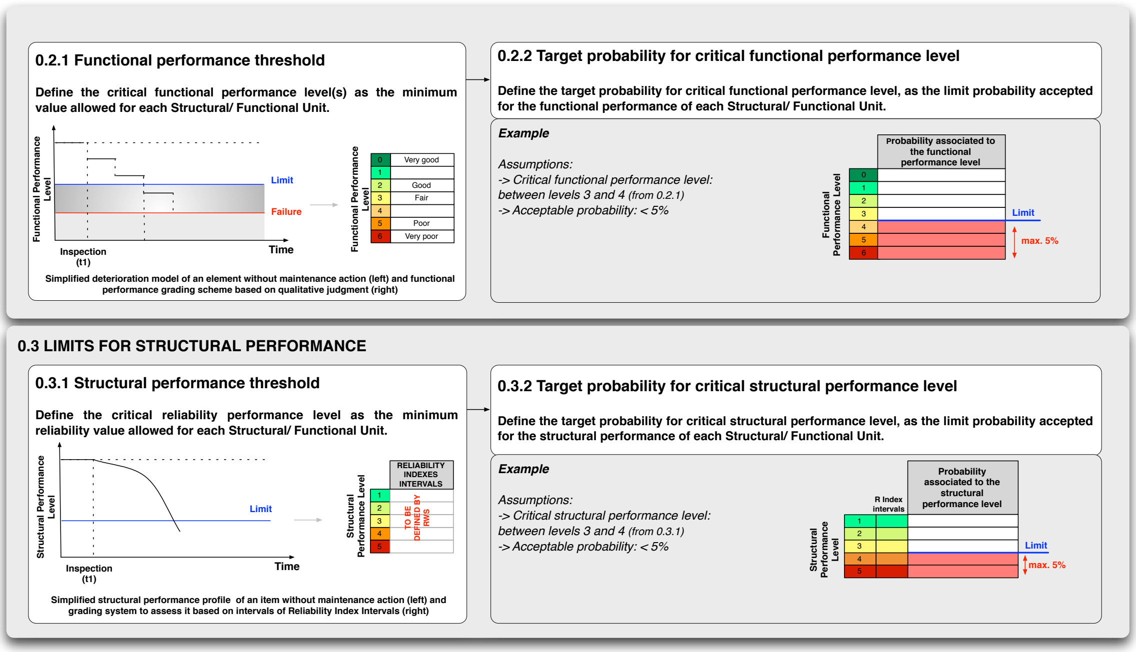



Figure 4.6 – Block 0.2 and 0.3: Limits for performance (extracted from the model)

The definition of such threshold is vital for two reasons. Firstly, they are the first indicator for performing a deeper risk analysis based on reliability assessments, as it will be explained in Part 1. For example, it might be the case that in a certain moment, a beam with a certain degree of corrosion, has some probability to lose its function and can no longer bear any load. These moments - or limits - must be specified and well understood. Secondly, these threshold are indicators for the need of possible maintenance actions; for example, essential maintenance actions might be needed when a performance threshold (i.e. functional or structural performance levels) reach a predefined limit. The threshold can be defined as deterministic or probabilistic indicators.

## PART 1. RISK PROFILES ON ELEMENT LEVEL

The objective of Part 1 is to define the risk profile of each element of the civil structure by making use of RAMS criteria. It is composed by the following parts: block I (reliability risk without maintenance), block II (maintenance actions), block III (reliability risk with maintenance), block IV (maintainability assessment), block V (safety assessment) and block VI (availability assessment).

### Reliability assessment without maintenance actions (Block I)

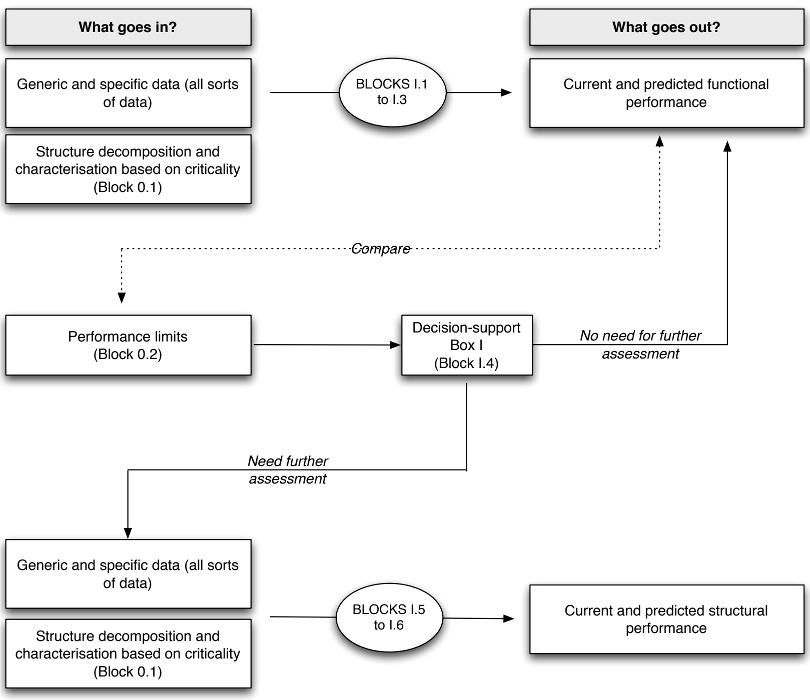



Figure 4.7 – Block I: Schematic input and output of the blocks

The goal of this block is to assess the current functional and structural performance levels of each element and the evolution of those levels over the reference period (Figure 4.8). Then, such levels must be compared with the set performance threshold (block 0.2).

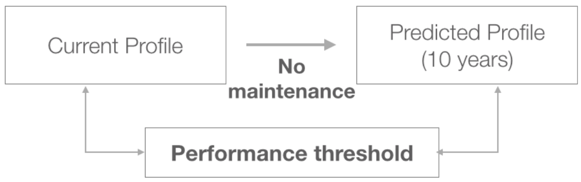



Figure 4.8 – Scheme illustrating the scope of Block I

The use of functional performance levels as the indicators of the need for maintenance actions is limited by the accuracy of visual inspections. Visual inspections are extremely useful in assessing the level of deterioration, such as cracking and spalling in reinforced concrete structures and corrosion or paint distress in steel structures. However, early stages of several deterioration mechanisms, such as fatigue, cannot be identified through visual inspections. Furthermore, the impact of initial safety, existence of non-observable defects and the time variation of loads, among others, cannot be identified by visual inspections alone.

Furthermore, in a visual inspection is not always possible to assess the impact of certain defects on the function of an element. For example, having 10% of corrosion condition on an element is clearly different from having 10% of performance risk; in fact, the amount of risk depends on the extent that the beam is capable to carry the load required. This sort of analysis is not possible by making use of inspection results alone.

A more detailed analysis can be done with reliability-based assessments, where all the significant deterioration mechanisms and load time dependency can be realistically modelled. Yet, if a detailed analysis for each element is required, these techniques do not only require intense working procedures, but also need a large amount of data. More, the cost of performing such evaluations for all elements in a structure is very high and its use is usually only reasonable for structures associated with significant deterioration for which reduction of structural safety can be expected.

As one of the underlying assumptions of this model, the analysis of functional performance levels is based on the condition assessed during inspection. Due to the relation between functional performance and structural performance, we assume that a risk is initiated when the functional performance reaches a certain threshold. In this case, if the risk associated with losing the function is high enough, it may lead us to believe that the function can no longer be provided. Therefore, based on the outcomes of visual inspections, analysts must check whether the function is affected or not and if there is a risk that such function is not provided anymore; then, there is a need for a more detailed analysis.

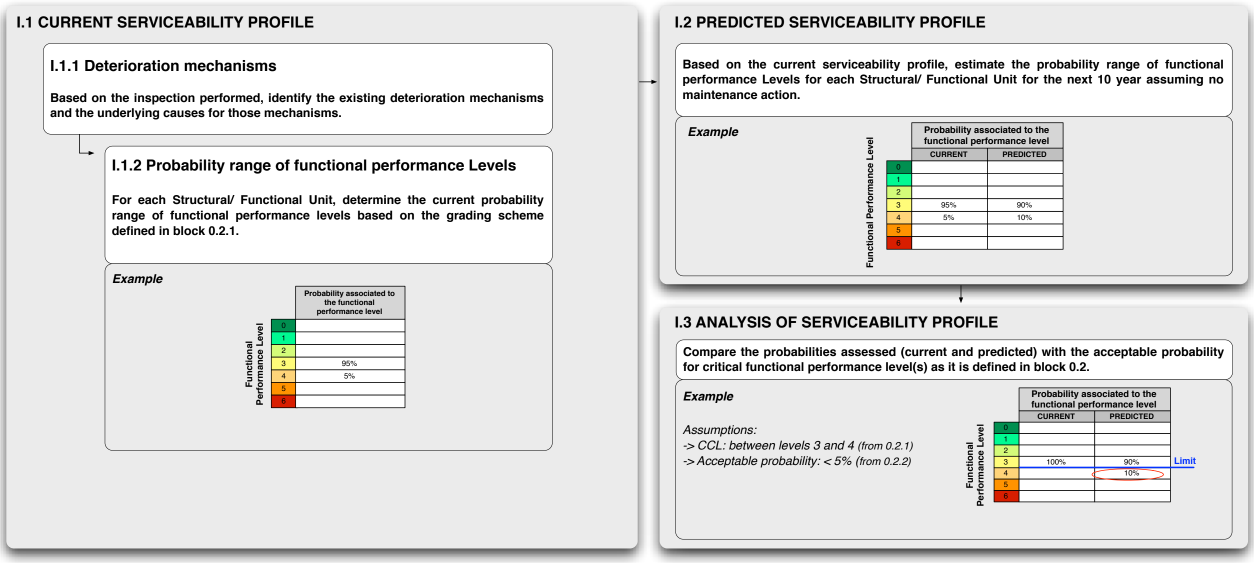



Figure 4.9 – Block I: Current serviceability profile (extracted from the model)

To consider such scenario, the model includes a decision-support box, where the verification of critical triggers is checked (Figure 4.10). These triggers are based on the criticality of the element under analysis, on the threshold of the structure, on the potential change of the current loading conditions (e.g. higher predictable traffic load), on the potential change of benchmarking conditions (e.g. change of design code or regulations) or even on the need to assess remaining lifetime of an element.

It is important to highlight that the functional performance level is considered as a continuous variable, based on the condition assessed during the inspection and based on the function of an element. On the other hand, the structural performance level is related to the reliability index of an element, which uses probabilistic indicators based on a certain number of random variables. The result of this block is a current and predicted risk profile of functional performance for each element (serviceability profile) and, if necessary, risk profile of structural performance based on probabilistic models. Both assessments must be performed under no influence of maintenance actions.

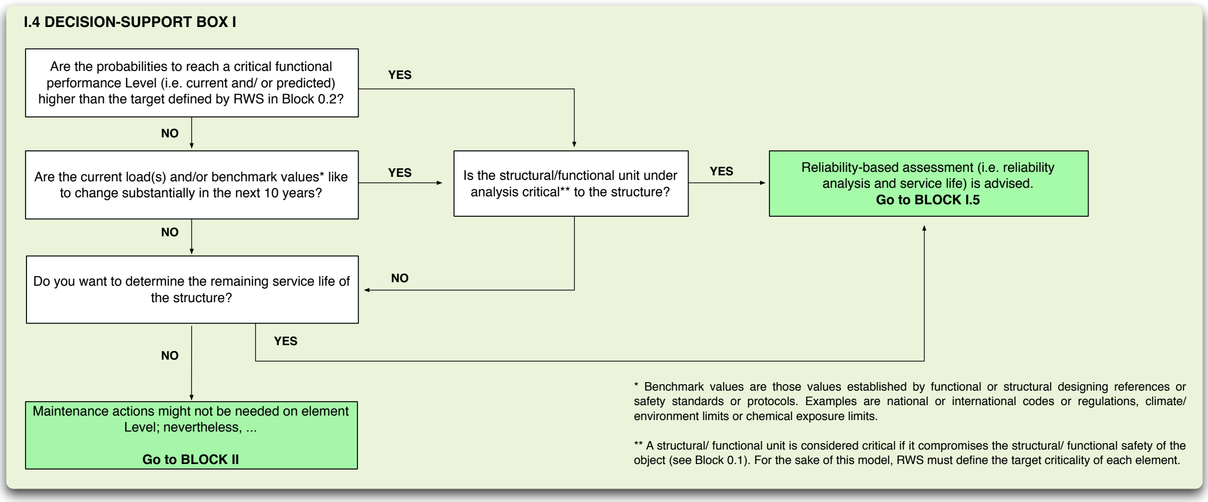



Figure 4.10 – Block I: Decision-support Box I (extracted from the model)

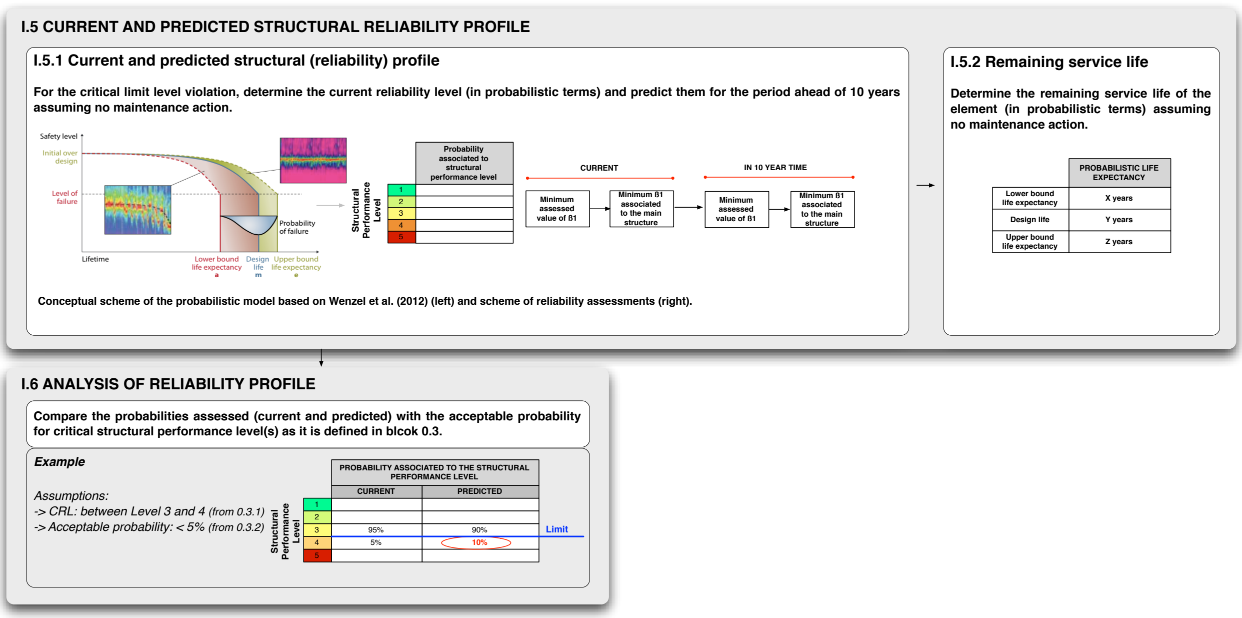



Figure 4.11 – Block I: Current structural reliability profile (extracted from the model)

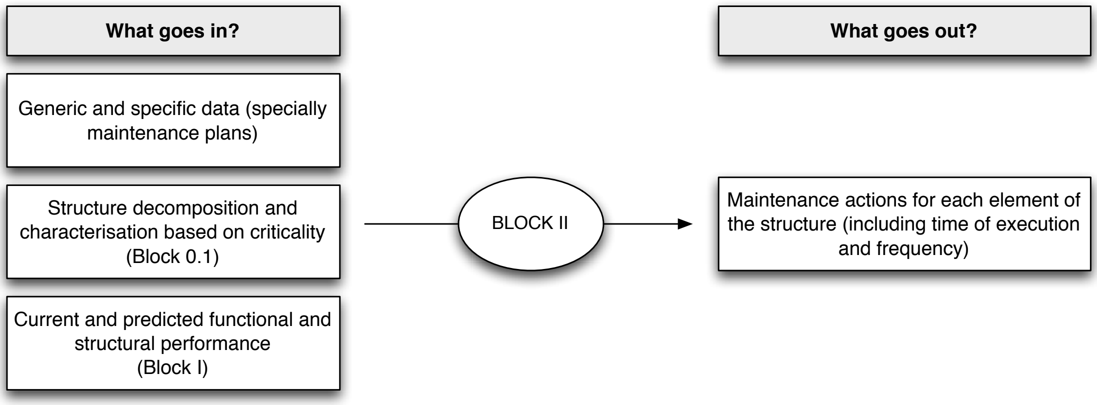


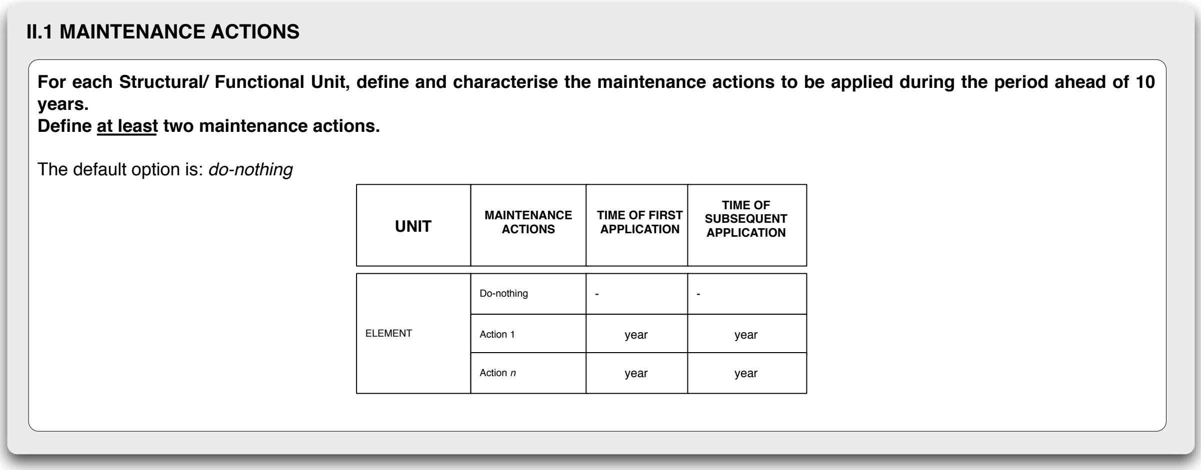

Figure 4.12 – Block II: Schematic input and output of the block

The implementation of a maintenance action leads to one, several, or all of the following effects (Neves et al, 2006: Frangopol & Neves, 2003): (a) increase in the condition state and reliability index immediately after application; (b) suppression of the deterioration in condition state and reliability index during a time interval after application; and (c) reduction of the deterioration rate of condition state and reliability index during a time interval after maintenance execution. According to Neves et al. (2006), the random variables defining these effects are: (a) increase in condition state and reliability index immediately after application, (b) time interval during which the deterioration process of condition and reliability is eliminated; (c) time during which the deterioration rate in condition and reliability is eliminated or reduced; and (d) deterioration rate reduction of condition and reliability. Alternatively, the reduction in deterioration of the condition index and reliability index can be defined by the deterioration rate during the effect of maintenance.

By being grounded on these theoretical aspects, this block focuses on the identification and characterisation of a set of maintenance actions defined for each element over the reference period. Such actions must be based on the principle that they can change the functional and structural performance level assessed in the previous block. The underlying idea is that analysts must define, at least, two maintenance actions to be implemented, including the default option of “do-nothing”. For each action, it must be defined the first time of application and the subsequent time of application. Table 4.2 provides an example of such characterisations.

Table 4.2 – Example of characterisation of maintenance actions

| DETERIORATION MECHANISM | ELEMENT | MAINTENANCE ACTION | TIME OF FIRST APPLICATION | TIME OF SUBSEQUENT APPLICATION |
|---|---|---|---|---|
| Corrosion damaged RC structures | Beams | Do-nothing | - | - |
| | | Patch repair with concrete surface treatment (silane) | 2015 | (+15 years)<br>- |
| | | Patch repair with calcium nitrate corrosion inhibitor | 2015 | (+7 years)<br>2022 |
| | | Complete rehabilitative overlay with cathodic protection | 2017 | - |



**II.1 MAINTENANCE ACTIONS**

**For each Structural/ Functional Unit, define and characterise the maintenance actions to be applied during the period ahead of 10 years.**
**Define <u>at least</u> two maintenance actions.**

The default option is: *do-nothing*

| UNIT | MAINTENANCE ACTIONS | TIME OF FIRST APPLICATION | TIME OF SUBSEQUENT APPLICATION |
|---|---|---|---|
| ELEMENT | Do-nothing | - | - |
| | Action 1 | year | year |
| | Action *n* | year | year |

Figure 4.13 – Block II: Maintenance actions (extracted from the model)

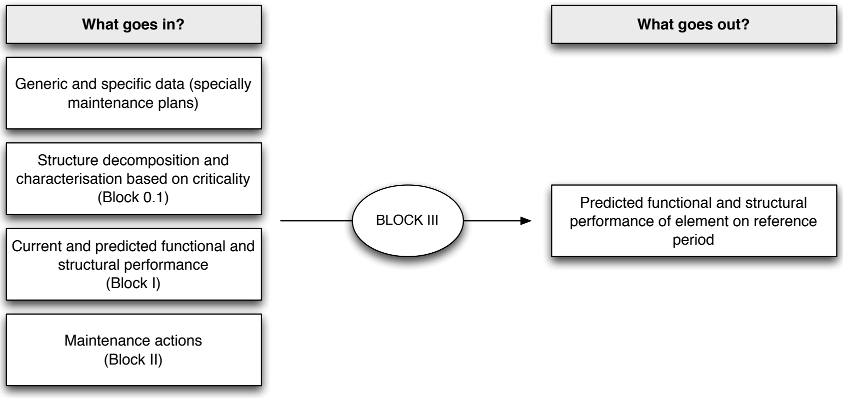



Figure 4.14 – Block III: Schematic input and output of the block

This block can be considered as an extension of the assessments performed in Block I. After the definition and characterisation of maintenance actions, analysts must determine their effect on the functional and, if necessary, on the structural performance level over the reference period. The underlying idea is to assess the potential improvement on the performance of the element due to the maintenance action. The outcome of this block must be presented in probabilistic terms.

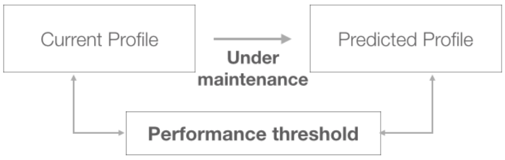
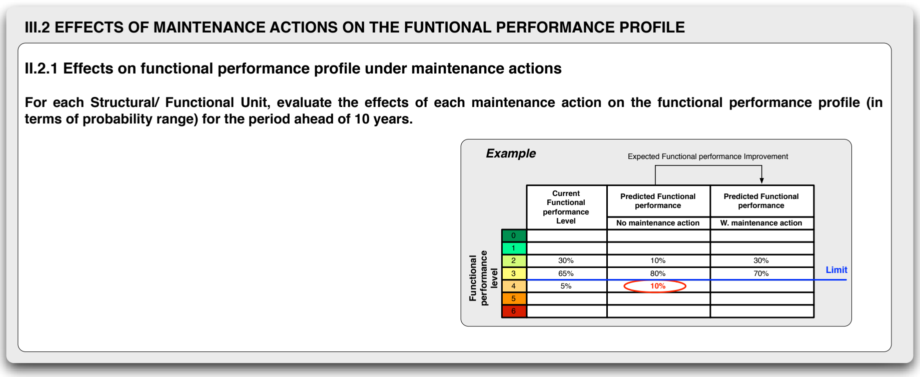



Figure 4.15 – Scheme illustrating the scope of Block III



**III.2 EFFECTS OF MAINTENANCE ACTIONS ON THE FUNTIONAL PERFORMANCE PROFILE**

**II.2.1 Effects on functional performance profile under maintenance actions**

**For each Structural/ Functional Unit, evaluate the effects of each maintenance action on the functional performance profile (in terms of probability range) for the period ahead of 10 years.**

***Example***

Expected Functional performance Improvement

| Functional performance level | Current Functional performance Level | Predicted Functional performance – No maintenance action | Predicted Functional performance – W. maintenance action |
|---|---|---|---|
| 0 | | | |
| 1 | | | |
| 2 | 30% | 10% | 30% |
| 3 | 65% | 80% | 70% |
| 4 | 5% | 10% | |
| 5 | | | |
| 6 | | | |

Limit

Figure 4.16 – Block III: Effects of maintenance on the functional performance profile (extracted from the model)

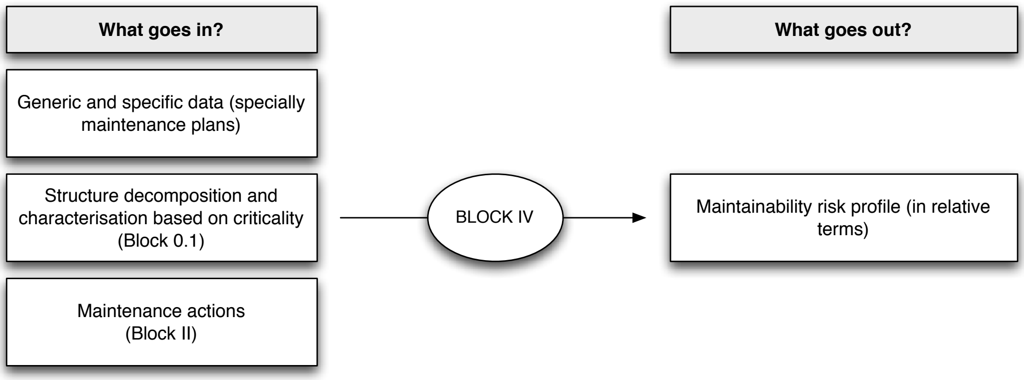



Figure 4.17 – Block IV: Schematic input and output of the block

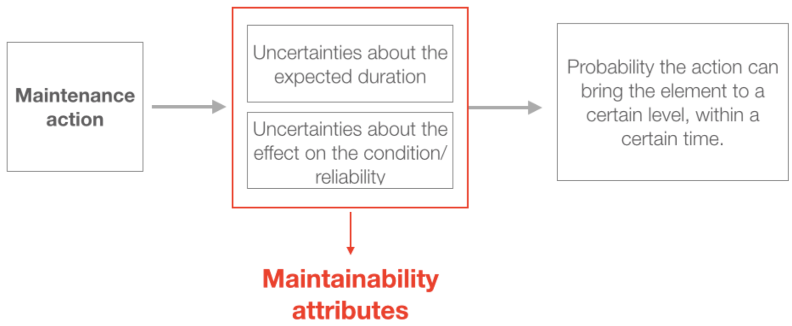



Figure 4.18 – Scheme illustrating the scope of Block IV

This block aims at defining the maintainability risk profile of the actions defined in Block III. For the sake of this model, maintainability is related to the capability of a specific action to bring the element to a specific functional and structural performance level over a reference period. However, there is uncertainty related to these capabilities, both in terms of the extent of upgraded performance and related to the time needed for the execution of the maintenance action.

Thus, the risk profile is determined in relative terms through the assessment of the probability that the element can be maintained within a certain time and the action can upgrade the element to a desired functional and structural performance level. The maintainability judgment must be based on the probability that a maintenance action takes longer (or not so longer) when compared to other maintenance alternatives and it can bring the element to a desired performance level.

For a relative analysis it is needed the definition of, at least, two maintenance actions. The main reason for the relative analysis is the lack of information about the duration of maintenance actions and also the difficulty to get such information. Analysts must select the factors that can influence the time aspect and those that affect the performance upgrading aspect. In Appendix 5, it is presented a comprehensive list of attributes that can be used to support the assessment of the maintainability criteria.

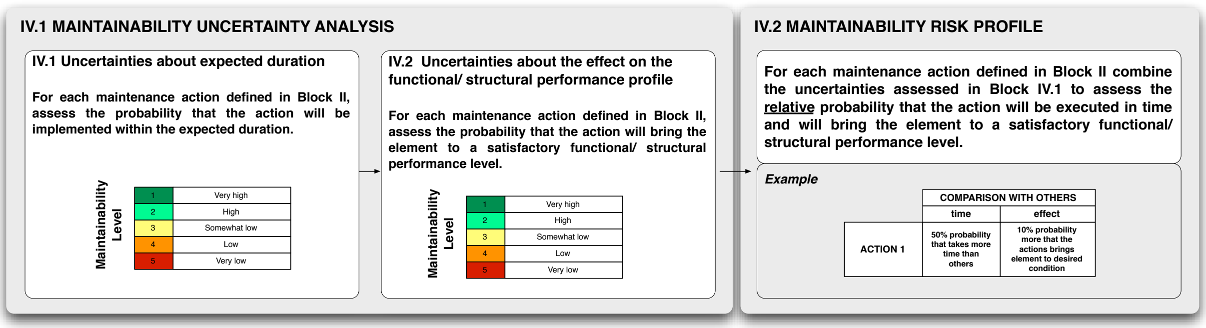



Figure 4.19 – Block IV: Maintainability assessment on element level (extracted from the model)

## Safety assessment (Block V)

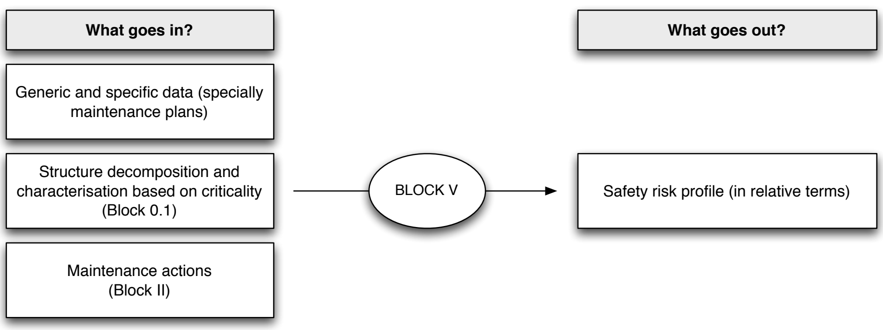



Figure 4.20 – Block V: Schematic input and output of the block

Usually safety is assumed as the state of technical system freedom from unacceptable risk of harm. Normally, in the context of operation and maintenance, safety of a civil structure has two main objectives: (1) safety for the public travelling through the asset (user safety); (2) safety for the maintenance staff during the execution of maintenance actions.

Although these aspects are critical to the general perception of the safety profile involved, some safety aspects are complex to assess during the maintenance programming. For example, the aspects related to the safety of the maintenance staff are usually allocated to the contractor awarded with the bid for the maintenance. The definition of safety aspects depends on the actions proposed by those private parties. From early stages of maintenance programming it is very difficult to determine the severity of the risk profile.

The underlying idea is to consider the improvement of public safety by evaluating direct and indirect health and safety impacts that are beneficial or detrimental to users of the service, as well as to the general public. Therefore, the goal of this block is to assess the probability of users to be involved in an accident, or incident, that leads to deaths, injuries or illnesses due to a deteriorated physical condition and/or reduced levels of service provided. This probability must be assessed considering the implementation of the maintenance proposed. To some extent, the safety risk profile is not specific to the action itself, but to the reliability level that the action will bring the element to.

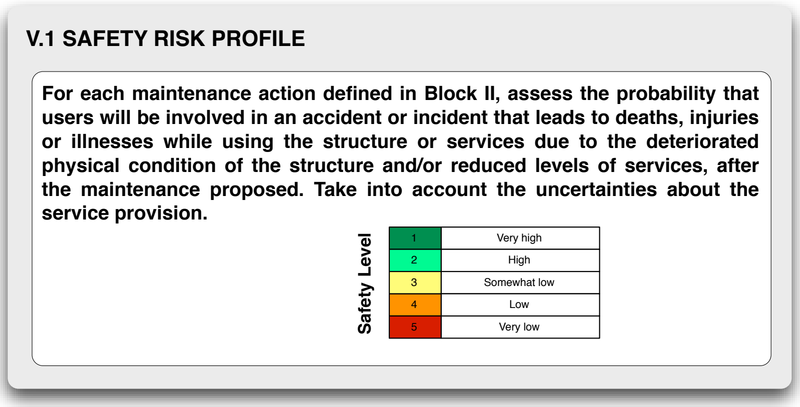



Figure 4.21 – Block V: Safety assessment on element level (extracted from the model)

## Availability assessment (Block VI)

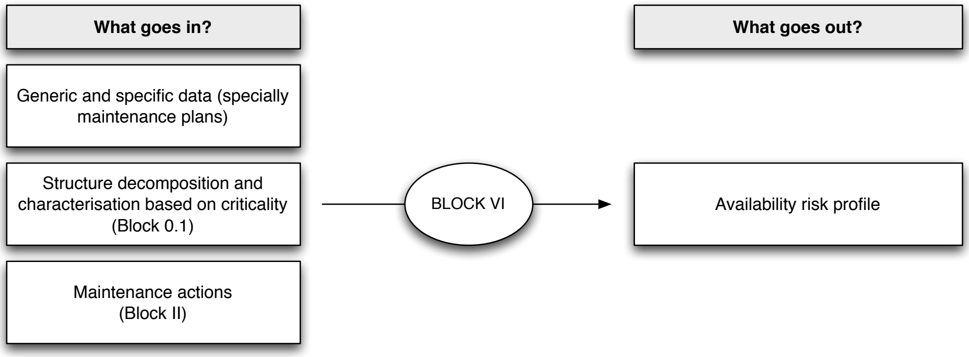



Figure 4.22 – Block VI: Schematic input and output of the block

In this model, availability is seen from the perspective of service available for users during the maintenance action. The emphasis is given to the effect of maintaining an element on the service provision. The underlying idea is to assess to which extent is an action more favourable to the level of service provision, during its execution, in comparison to the remaining alternatives. Thus, to determine the availability risk profile on the element level, it is necessary to consider the set of maintenance actions defined. To this end, analysts must consider the uncertainties related to the time of execution (e.g. action 1 needs more time than action 2) and the level of service provision (e.g. whether it is necessary to close the structure or not). The availability risk profile must be also defined in probabilistic terms.

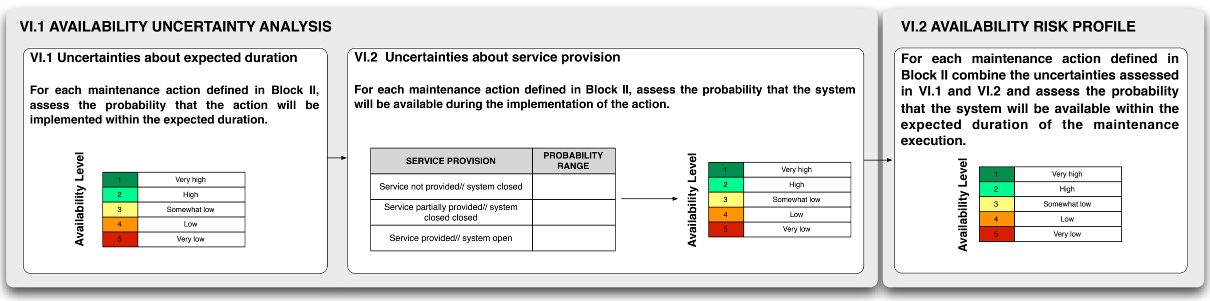



Figure 4.23 – Block VI: Availability assessment on element level (extracted from the model)

## PART 2. RISK PROFILES ON STRUCTURE LEVEL

The goal of part 2 is to characterise the risk profile of a structure and select a maintenance strategy that satisfies the performance limits defined by RWS. Part 2 is composed by the following blocks: maintenance strategies (block VII), availability assessment (block VIII), reliability assessment (block IX) and maintenance strategy (block X).

### Maintenance strategies (Block VII)

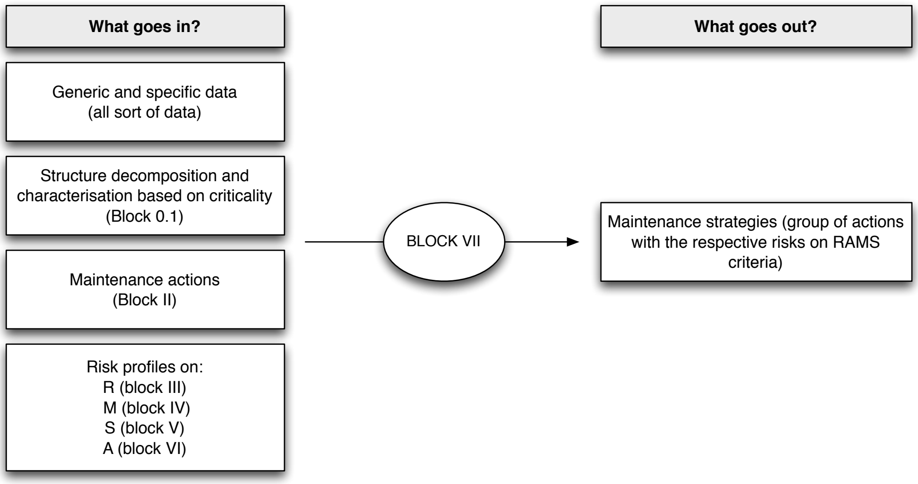



Figure 4.24 – Block VII: Schematic input and output of the block

As it is being emphasised, existing civil structures may be subjected to different types of hazards with very different likelihoods and consequences during their life cycles. In fact, the risk profiles determined in Part 1 are precisely based on the probability of potential failures on the element level. However, most structures are an assembly of structural elements and the risk profile of a structure is not necessarily equal to the most critical risk identified on the element level.

Furthermore, different risk mitigation strategies that are implemented to improve the performance of critical elements are usually assembled in a group of actions (or project) to be tendered to private contractors. This means that maintenance actions on the element level are not necessarily implemented at the exact time defined during the risk assessment. Therefore, an overview of the risks profiles on the structure level is needed.

In this block, analysts must characterise a set of different maintenance strategies (i.e. group of actions selected strategically) to reduce the risk of failure of the structure. For each element, the maintenance actions selected must be based on the risk profiles identified in the first part. The goal is to have a set of actions that are applied to the elements of the system within a certain period; the strategy defines the combination of these actions (i.e. when it is done what and when to combine actions). After having such definition for all the elements of the structure, we combine them on a strategy, which results on a certain risk for the system.

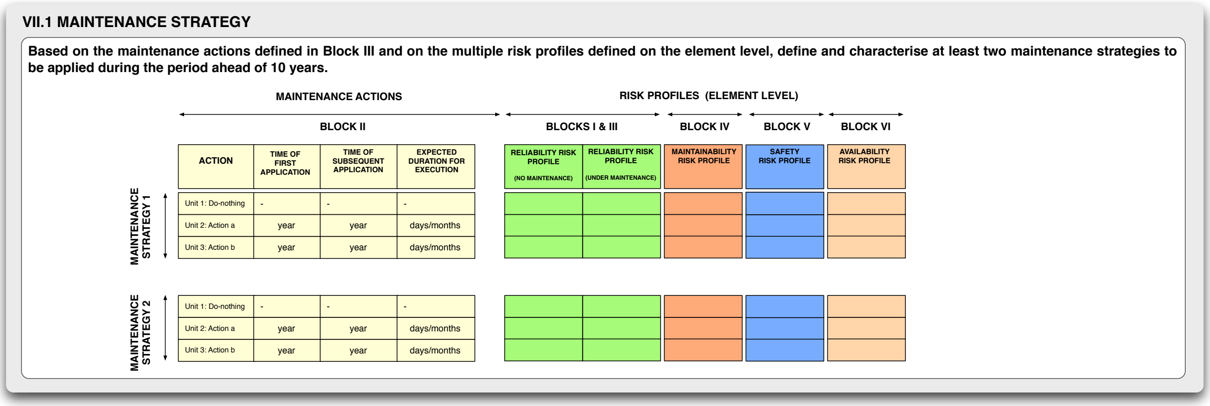



Figure 4.25 – Block VII: Maintenance strategies (extracted from the model)

## Availability assessment (Block VIII)

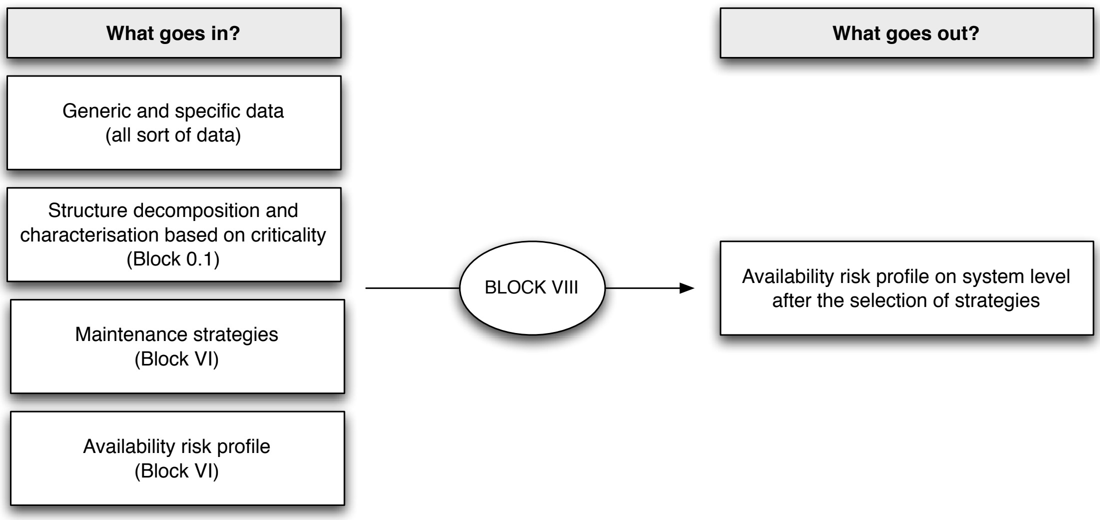



Figure 4.26 – Block VIII: Schematic input and output of the block

At the strategy level, the reassessment of risks is vital to validate the risk profiles related to the maintenance actions combined in a strategy. This is particularly relevant for the availability risk profile, since the level of service provision might be affected as a result of the combination of a group of actions. For example, it can be the case that a certain action is defined to be regularly applied every 5 years; however, from the perspective of service availability, it is more beneficial if a more robust solution is applied once every 10 years. On the element level, it can be the case that small actions are more favourable in terms of availability, but when a strategy is considered over a certain period of time, a more robust action might be more favourable. This sort of analysis is transferable to the system level, when multiple elements are considered. Another example is that based on risks it is concluded that element A needs intervention on year 3 and element B needs intervention on year 5. As a result of the combination, the maintenance measure is proposed to be implemented on year 4.

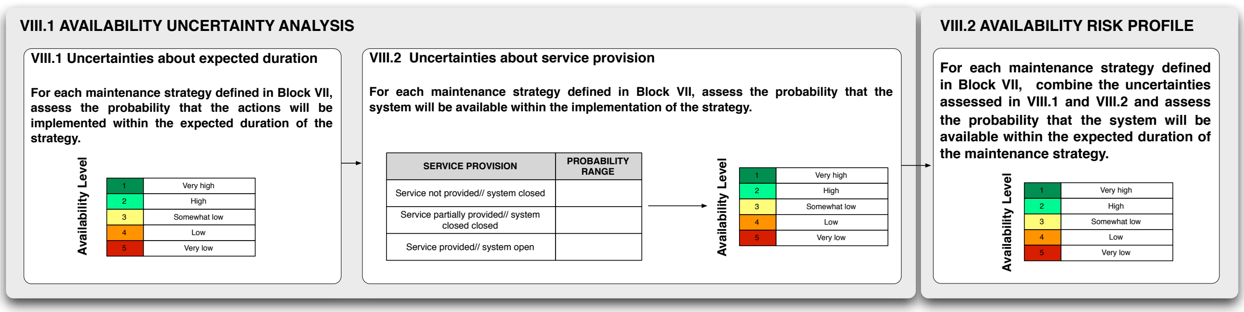



Figure 4.27 – Block VIII: Availability assessment on element level after strategy (extracted from the model)

## Reliability assessment (Block IX)

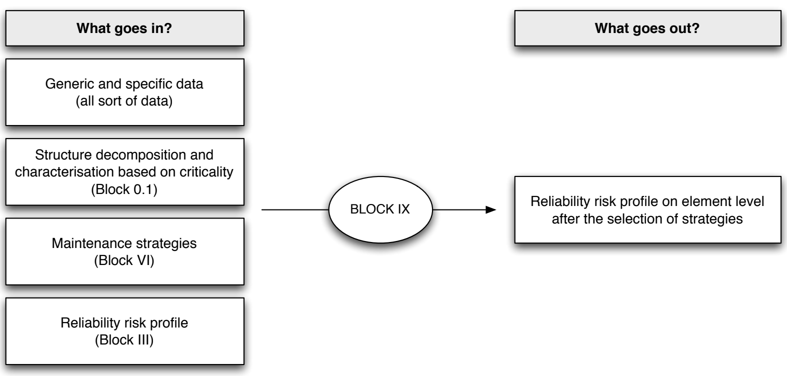



Figure 4.28 – Block IX: Schematic input and output of the block

As part of the maintenance strategy on the structure level, a set of maintenance actions are specified to be applied within a certain period of time. The combination of actions can imply that the respective time of implementation can change relatively to the initial assessment. As a result, other risks can be affected, as it is the case of reliability. For example, by postponing the implementation of a specific measure on an element, the risk profile might change in comparison to the time defined in the initial assessment. Thus, in this block, the reliability risk profile of elements must be reassessed.

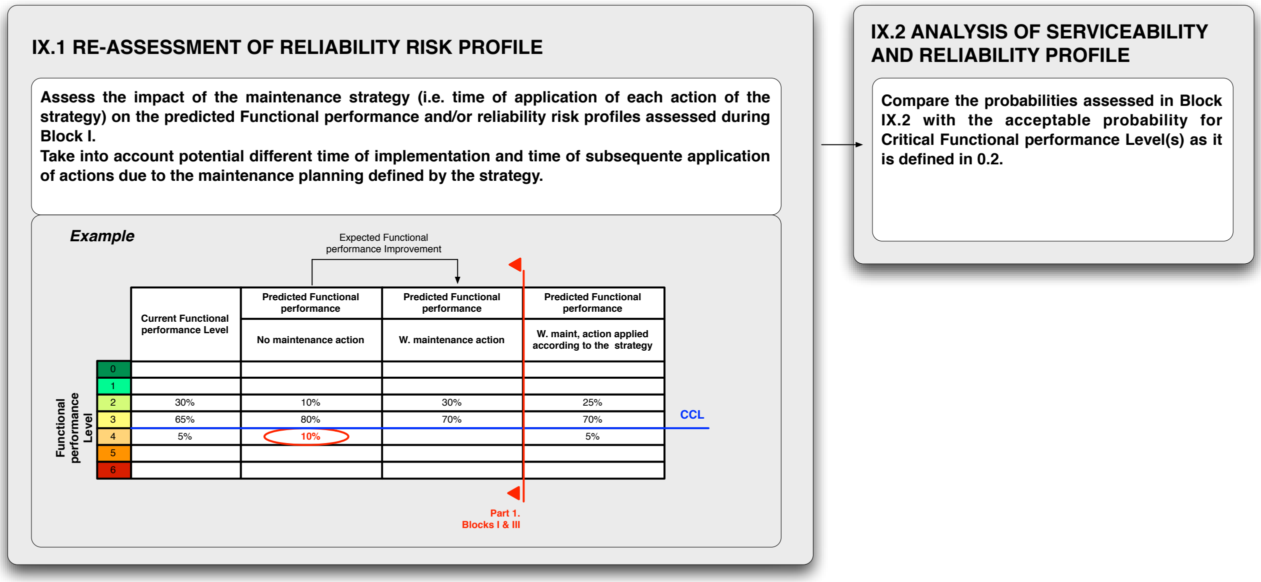



Figure 4.29 – Block IX: Reliability assessment on element level after strategy (extracted from the model)

## Maintenance strategy (Block X)

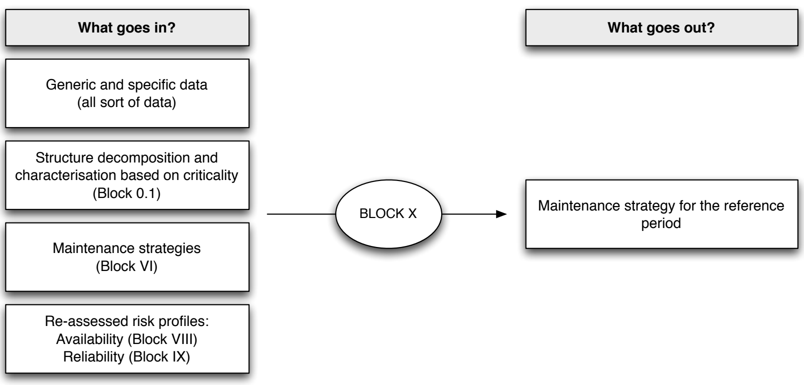



Figure 4.30 – Block X: Schematic input and output of the block

The final block of this model aims at selecting a maintenance strategy that satisfies the risk limits defined by RWS. The underlying idea of this bock is to check whether a maintenance strategy can be selected based on risks. Since this model has an open-ended nature, the set of maintenance strategies can be iteratively redefined until the risk limits are satisfactory.

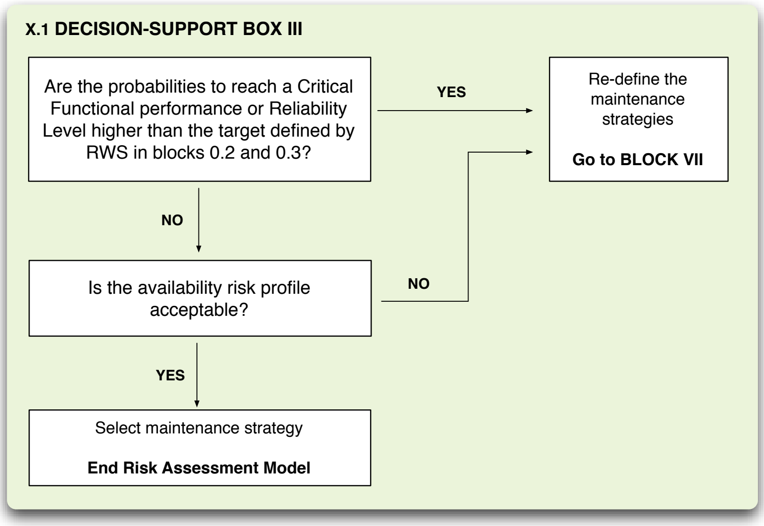



Figure 4.31 – Block X: Maintenance strategy (extracted from the model)

## VERIFICATION AND VALIDATION

For the validation of the model, we organised an expert-based workshop with professionals involved in inspection and/or maintenance processes. The workshop aimed not only to validate the model, but also to identify and discuss its limitations and potential difficulties for implementation. The handout of the workshop and the respective list of attendees is presented in Appendix 6.

### Verification

As part of the model verification, we compared the design requirements defined in Chapter 3 with the model outcome, as it follows:

Table 4.3 – Design specifications *vs*. verification

| # | REQUIREMENT | VERIFICATION ? | |
|---|---|---|---|
| 1 | Definition of a model to support managers to understand the RAMS criteria involved in the risk assessment of civil structures and the relationship between the set of them. | Yes, the design model - a risk assessment model - is based on RAMS criteria. Each criteria has dependencies between each other. | ✓ |
| 2 | The model must support maintenance programmers to define the risk profile of a structure and to rank such risks in relative levels. | Yes, the model was designed to support maintenance programmers to assess risk. The relativity is assumed through dependencies. | ✓ |
| 3 | The model must include element and object level. | Yes, the model structure includes element and object level. It also includes a block to study the relationship between element and system (block 0). | ✓ |
| 4 | The relationship between elements must be clear. | | |
| 5 | The data/ information generated during the usage of the model should be stored in the current data management system as a support to further inspections and maintenance processes. | The results of the model must be stored in the DISK database. However, this requirement must be addressed to the implementation phase.<br>*This requirement is addressed for further developments of this study. Thus, its non-fulfilment does not imply the rejection of the model developed.* | ✗ |
| 6 | All the subjects involved in the processes of inspection and maintenance programming should be able to understand and interact with the model. | Yes, this is exactly the aim of the model since it is based on the assumption that the practitioners involved in the inspection and maintenance process must contribute with expert data to the model. | ✓ |
| 7 | The model procedures must be compatible with the current inspection model and with the current maintenance programming process. | Yes, the current procedures were considered as the basis for the model design. | ✓ |
| 8 | The model must give the programmers a clear indication not only of the condition of each asset, but also about the level of its structural capacity. | Yes, through the reliability blocks. | ✓ |
| 9 | The model outcomes should be valid for a reference period ahead of the inspection time. | Yes, it is part of the model assumptions to assume a reference period. In this case, it was considered 10 years, but it can adjusted by RWS. | ✓ |
| 10 | The model should incorporate the possibility to be extended to a network level of analysis. | Yes, the model can be further extended with other criteria, such as cost blocks, which will allow for a network level of analysis. | ✓ |

### Validation

One of the main goals of the final workshop with representative DISK data users was to validate the risk assessment model developed. To some extent it can be said that the workshop acted as a discussion arena where practitioners could identify and discuss potential limitations of the usage and implementation of the design model.

RWS emphasised that this study resulted a very useful model. By making use of this general guideline, RWS has a decision support tool that guides what must be done in terms of specific risk assessments. However, despite the general satisfaction of the practitioners, the model introduces a set of procedures that practitioners are not yet familiar with. In fact, the advancement of the model concept is quite different from the current way of working within the organisation. Although this limits an immediate implementation, the model helps to better understand the whole risk assessment process. It provides guidance and support to further and more detailed steps in the risk assessment model. Yet further developments are needed and to that RWS must be selective on relevant aspects of the entire risk assessment model due to the impossibility to use a “one size fits all” tool. As a result, more detailed tools must be developed to cover the specific needs of some structures.

# CHAPTER 5. CONCLUSIONS

The maintenance of civil structures is a vital aspect for any managerial transportation agency. Data is a key enabler for any maintenance related decision process. The role of data, its properties and the manner that data is used during those decision processes are vital aspects to its successful implementation.

In RWS, despite the efforts on improving the effectiveness of risk-based asset management for maintenance purposes, risk seems to not be yet well understood among distinct decision-makers. This is particularly relevant to those processes that use data collected and stored in DISK: the existing database for civil structures.

In the context of RWS, we developed a risk assessment model based on RAMS criteria for decision support of maintenance programmers. The main goal is to support these practitioners to translate data collected from inspections into a risk-based language that can be understood by maintenance programmers. The model uses the data collected and stored in DISK during the inspection process to assess the risk profiles of structures and their elements based on RAMS criteria. By including the default option "do-nothing", the maintenance strategy includes the worst case scenario and provides a more accurate risk picture. The outcome of the model is a maintenance strategy to be applied on the structure and its elements, within a reference period.

This model is an open-end tool that allows the user to go backwards on the risk assessment to identify the effects of a specific maintenance action both on the element and on the structure level. To some extent, we can say that it is a sort of iterative process that provides risk-based feedback on a set of possible maintenance solutions over a time period. This is particularly interesting since risks are assessed by considering the interrelationship between RAMS criteria. In fact, we tend to believe that this is exactly the core contribution of this model: it gives RWS grounds to re-think the risk-based process by aligning the current practices to a more applicable and effective risk concept. In addition, it provides guidance to the further steps in terms of specific risk assessments.

Despite the potential of the design model, we are aware of its limitations. Thus, we identified the main limitations of the model that must be further addressed in future work.

Firstly, the model is based on a concept that needs to be implemented in the organisational context. Despite being grounded on the processes used in RWS, it still needs to be adjusted to all the real-base cases of the organisation. Thus, we strongly advise to apply the model to a representative number of civil structures in order to identify and overcome potential implementation barriers.

The model does not include the translation of inspection results into a condition level. The deterioration mechanisms and their relative effect on the process of decreasing the properties of the element are not specifically present in DISK or in the inspection and maintenance processes. Then, it is also difficult for inspectors to translate the current condition to a specific level of functional and / or structural performance. This means that the problem of subjectivity during visual inspection is still unsolved. We suggest the development of a tool that supports inspectors to translate their condition assessment (on the element level) to a functionality performance level. This can be done, for example, through checklists that relates each element's condition to a functional level. Since the goal is to translate condition into function, concurrently with the checklist, it is also necessary to structure a set of indicators that helps to define the respective condition.

We also suggest to continue the current RWS's efforts on implementing inspectors training and certification. The goal is to familiarise practitioners with a risk-based approach used within the organisation and guide them into similar assessment procedures.

Another limitation is the lack of cost considerations, since maintenance actions and strategies are just based on risk. However, the selection of an optimal maintenance strategy, based on short and long-term perspectives, must also consider costs. Thus, costs must be addressed to the model. This can be done with the support of other probabilistic tools, as Pareto Analysis, that when calibrated can help to find an optimal maintenance strategy within a specific scenario.

Finally, we suggest that the model can be further enlarged to other phases of analysis, particularly during the implementation of maintenance actions. Since the procurement procedures allows the contractor to provide their own traffic and safety actions for the period during the inspection, the risks involved could be particularly (re)assessed for this point in time. The goal was to give a more accurate picture of risks outside of the maintenance programming frame but also through the maintenance execution phase.

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# APPENDICES

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- Appendix 2: Interview protocol
- Appendix 3: Report with interviews results
- Appendix 4: RAMS model
- Appendix 5: List of potential maintainability attributes
- Appendix 6: Workshop handout

## APPENDIX 1

## REPORT WITH DISK CHARACTERISATION

*Number of pages: 87*

# OPPORTUNITIES TO SUPPORT ASSET MANAGEMENT DECISION-MAKING PROCESS THROUGH THE DISK DATA SYSTEM

*"Potentiëlen voor de ondersteuning van Asset Management beslissingen bij kunstwerken".*

---

## PART 1.

## CHARACTERIZATION OF DISK DATABASE SYSTEM.

## DATA STORED AND RESPECTIVE PROCESSES FOR DATA COLLECTION

(PRELIMINARY FINDINGS)

**Professional Doctorate Engineering Program**

T.C. Viana da Rocha *(University of Twente)*

Program Advisors:

Dr. ir. A. Hartmann *(University of Twente)*

Dr. ir. R. Schoenmakker *(Rijkswaterstaat)*

Enschede, June 2013

Final Version

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## 1. CONTEXT AND OBJECTIVES.

### 1.1. Introduction.

DISK *(Data System Works)* and its extension MIOK *(Multiannual Planning Inspection and Maintenance Works)* is an (individual) management system owned by *Rijkswaterstaat*. DISK is used to store and to manage all relevant technical and administrative data related to infrastructure objects. This includes physical objects that are part of the national networks managed by *Rijkswaterstaat* (i.e. highways and water network), such as bridges, tunnels, viaducts, culverts, locks and dams *(in Dutch: kunstwerken)*.

This document follows an initial *Research Proposal* produced in the context of a PDEng program developed between *Rijkswaterstaat* and the University of Twente. The purposes of this analysis is to provide answer to the first research (sub-)question defined in that preliminary document.

This comprehensive analysis is based in two main perspectives. Firstly, the data stored in DISK database system *(content)* is characterized. Secondly, the analysis focuses on the processes through which these data is generated, or collected, and then stored in the database *(process).* The scope of this analysis is presented in Figure 1.

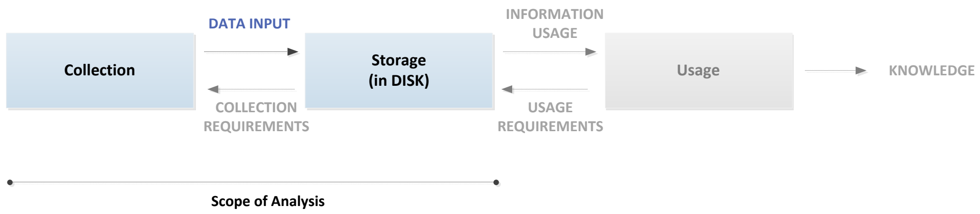


**Figure 1 – Scope of Analysis (first research question).**

### 1.2. Background.

#### 1.2.1. Research objectives.

The objective of this research is to improve the *effectiveness* of internal decision-making processes through the use of data collected and stored in the DISK database system, by:

1. Defining quality criteria to analyse the current capabilities of the storage system (DISK database) and the data collected.
2. Identifying and evaluating potential for data collection processes and, or data stored in DISK and design a possible improvement, either to the data collected and its characteristics, and/ or to processes through which this data is achieved.

#### 1.2.2. Research question and sub-questions.

In order to accomplish the research goals proposed, the following research question was structured:

***How to improve the effectiveness of internal decision-making processes through the use of data collected and stored in the DISK database system?***

This research question was decomposed in a set of sub-questions. The first research question, to which this analysis is referred to, was defined as it follows:

**1. How is the existent data system (DISK) characterized in the context of *Rijkswaterstaat* organization?**

*a. What is the data collected, stored and managed in the existent data system (DISK)? What are the data characteristics or properties? (data)* *b. How and when is the data collected and stored in the existent data system (DISK)? (processes)*

### 1.2.3. Research methodology (context).

By considering the research methodology structured in the *Research Proposal* aforementioned, the analysis presented in this document is part of *Phase 1*. Figure 2 illustrates the research methodology proposed with indication of the current *state of affairs*.

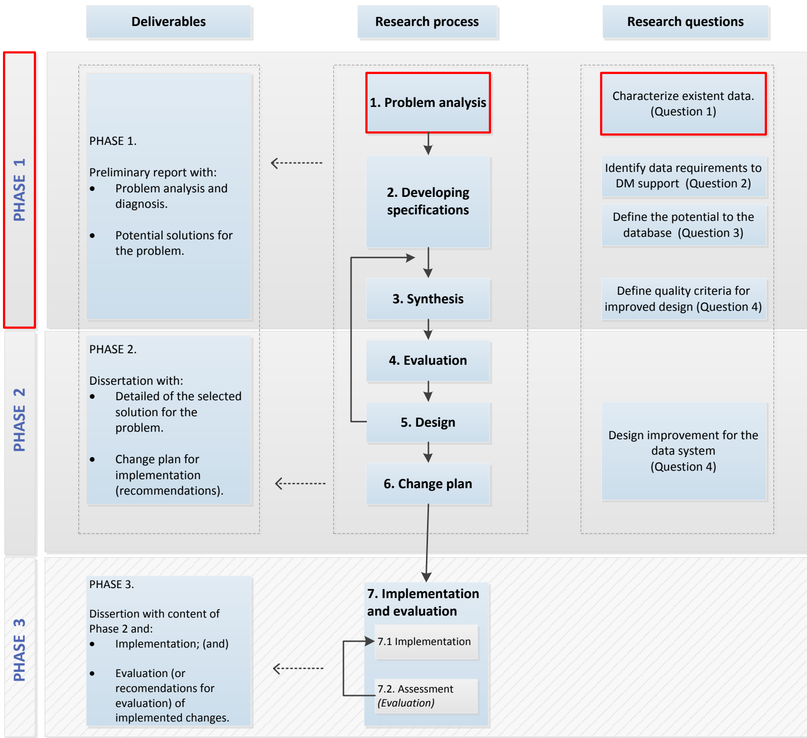


**Figure 2 – Research Methodology. Current research position.**

### 1.2.4. Organization of the document.

This document starts with the characterization of data stored in DISK (Chapter 2). It follows a description of the main processes that contribute to the flow of data stored in DISK (Chapter 3). Then, the focus in on the processes that contribute to generate and collect data stored in DISK (Chapter 4). This document ends with an overview on the main findings of this analysis (Chapter 5), and provides an input for the *follow-up* tasks of this research project (Chapter 6). *(Figure 3)*

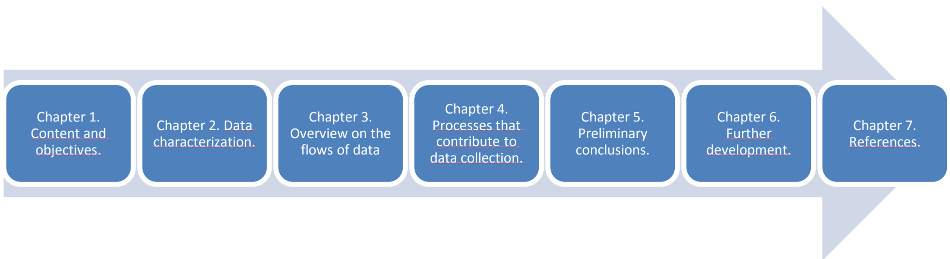


**Figure 3 – Outline of the document.**

## 2. CHARACTERIZATION OF DISK AND ITS DATA.

### 2.1. DISK characterized by IABMAS.

A basic management system includes functions, processes and outputs that are usually in line with needs of transportation agencies [9.]. The definition of these systems depends on different aspects, such as: distinct management policies, target service levels, characteristics of transportation systems and operational functions, or different environment conditions [16.]. These differences seems to bring difficulties in the adoption of a standardized database system within transportation agencies.

IABMAS is a commission of bridge management system (BMS) experts, in which the Netherlands is represented by *Rijkswaterstaat*. The main goal of IABMAS is to combine BMS knowledge, and to better understand differences between those BMS, by investigating in detail how others have done or are doing, or what they are planning to do [11.]. Simultaneously, IABMAS aims to create a network of BMS users, by identifying contact persons in each country. Recently, this organization compiled and published the current *state of the art* of BMS used within their member states. To this end, IABMAS predefined a set of (standard) categories, in order to facilitate the comparison between systems.

Due to this comparative nature, the study performed by IABMAS (which includes the database DISK), is used in this report as a theoretical reference to the current analysis of DISK database. Figure 4 illustrates the categories defined by IABMAS:

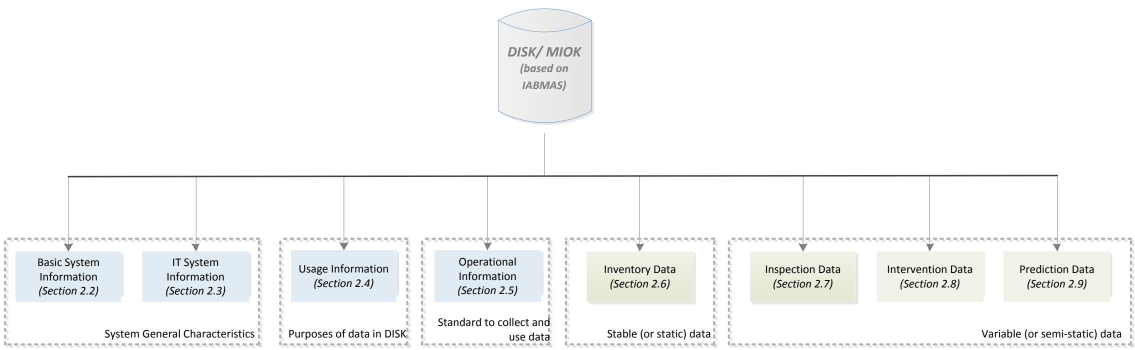


**Figure 4 – DISK characterization. Categories for system analysis and data analysis.**

The first four categories *(Figure 4: in blue)* aims to characterize the DISK system and their users. A second group of categories *(Figure 4: in green)* analyses the features of data collected and stored in DISK. Each of these categories are discussed in the next sections.

### 2.2. Basic (general) system information.

Basic general system data aim to characterize the DISK system according to three aspects: (1) level of system ownership, (2) the years of the first and current version of the system, and (3) number of users of the system.

#### 2.2.1. Level of system ownership.

DISK database is a system owned by *Rijkswaterstaat* (Central Administrator), developed and implemented on a national level. However, the responsibility for the infrastructure objects is somehow decentralized to regional/ local Administration services of *Rijkswaterstaat*. Each regional service is responsible for the management of objects located in their area of jurisdiction. Each regional service and district (referred to both networks, water and highways) has a contact person allocated by the Central Administrator. These areas are:

- RPC North East (RD East and RD North Netherlands and RD Ijsselmeer);

- RPC North West (RD North Holland and Utrecht);
- RPC South West (RD South Holland and RD Zealand);
- RPC South East (RD Limburg and RD North Brabant).

### 2.2.2. First and current version of the system.

DISK was initially developed in 1985 with the purpose to record data about (physical) infrastructure objects. In 2006, the system was adjusted to include condition assessment data provided by regular risk-based inspection activities. The database was adjusted to include also mitigation (maintenance) measures, and respective gross costs, which are dependent on preliminary inspection findings performed on object level[1]. The version updated in 2006 is still being used in *Rijkswaterstaat*.

### 2.2.3. Number of users of the system.

DISK is considered a single user database system in the sense that it is exclusively used to support processes within *Rijkswaterstaat*. Nevertheless, the database (or, parts of it) can be temporarily accessed by other parties, such as inspection agencies or design teams. The main DISK users and their relationship with data stored are detailed in the next table:

**Table 1 – DISK users. Role and relationship with data.**

| DISK users | Relationship with data stored in DISK/ MIOK | Main role |
|---|---|---|
| Administrators | Input<br>Output | - Central organism responsible for systems networks (legal owner).<br>- Responsible to define standards and rules for DISK database management and provide user's access (through DISK Helpdesk).<br>- Object registration, which is achieved through the following activities:<br>*a. First phase registration of an object in the system;*<br>*b. Supporting further registration of the fixed data area;*<br>*c. Initiation and support verification of Complex data;*<br>*d. Assessing changes provided by third parties;*<br>*e. Assessing regulatory compliance.*<br>- Use the data for maintenance optimization, prioritization and programing (outside DISK, through other database systems). |
| Regional divisions (districts) | Input<br>Output | - Responsible for the object maintenance and inspection processes.<br>- Responsible for data management and its accuracy, regarding inspection and maintenance processes. |
| Specialist departments *(example: CT and SWI)* | Input | - Specialist units define relevant registration data, including:<br>*a. Naming objects,*<br>*b. Design data,*<br>c. *Bearing capacity factors.* |
| Inspecting agencies (including inspectors of special transportation) | (Mainly) Input<br>*(Output, to prepare inspection processes)* | - Responsible to collect and store condition data of objects included in the cluster procured between them and the central Administrator. |
| External designers/ contractors | Output | - Use data to support objects design/ construction process. |
| Helpdesk DISK/ MIOK *(Part of central Administration)* | Control and User support<br>Access and database management | - Responsible to give access permit and IT support to different DISK users.<br>- Use quality criteria (defined in the GLP[2]) to validate data received and to periodically send data to other systems inside *Rijkswatertstaat*. |

[1] *Object Level* means per object included in a specific infrastructure network (highways or water network).

[2] GLP: Gegevens Levering Protocol

### 2.2.4. Resume of basic (general) system information.

The next table resumes basic system data about DISK, as defined by IABMAS [11.].

**Table 2 – Resume. DISK basic system information. [11.]**

| Name | | DISK/ MIOK |
|---|---|---|
| Basic data | **Aspect** | **Description** |
| | Owner (webpage) | Rijkswaterstaat (Dutch Ministry of Infrastructure and the Environment) (www.rijkswaterstaat.nl) |
| | Date implemented (current/ first version) | 2006/ 1985 |
| | Developer(s) (webpage) | Rijkswaterstaat (www.rijkswaterstaat.nl) |
| | References, Manuals and Catalogues | Users' manual DISK/ MIOK (Administration manual) (available in DISK helpdesk DISK @rws.nl in Dutch) |
| | Users (Principal/ Other) | Rijkswaterstaat (Dutch Ministry of Infrastructure and the Environment), Network data: National highways and Water Network |

## 2.3. IT system information.

In this section, the DISK database is characterized in terms of technologic aspects, including: (1) type of architecture, (2) reporting capabilities, and (3) mode of data entry and web assess.

### 2.3.1. Type of architecture.

In the type of architecture, the system logic design model (architecture tiers), the DISK (main) structure and its IT functions are described:

#### Architecture tiers:

The logic design model of DISK is considered a three tier system. The essential components within a *three* tier architecture are: (a) the Client PC, (b) the Application server, and (c) the Database server. This means that any of the three tiers can be upgraded or replaced independently. The user interface is implemented through a notebook connected to *Rijkswaterstaat*, and uses a standard graphical user interface with different modules running on the application server. The relational database management system on the database server contains the computer data storage logic. The middle tiers are usually multitiered [48]. The three tiers of this type of architecture are [48.]:

(1.) **Presentation (or client) Tier**: Occupies the top level, displaying data related to function available on a system. This tier communicates with other tiers by sending results to the browser and to other tiers in the network.

(2.) **Application Tier**: Also called the middle tier, logic tier, business logic, or logic tier. This tier is pulled from the presentation tier. It controls application functionality by performing detailed processing.

(3.) **Data Tier:** These tiers house database servers, where data is stored and retrieved. In this tier data is kept independent of application servers, or any business logic.

#### DISK structure and functions:

According to DISK user manual [30.], the database was developed in order to: (1) be a user-friendly method to fill and handle condition of structures, (2) to always provide a direct view of the status of an objects through a relationship *condition - measure*, and (3) to easily maintain and manage data stored.

To achieve these goals, DISK was structured in a way that allows interaction with users through four (main) functions: (1) read *(in Dutch: lezen)*, (2) add *(toevoegen)*, (3) remove *(verwijderen)*, and (4) modify *(wijzigen)*. The next figure illustrates DISK (user) categories, and the following table describes the respective DISK functions.

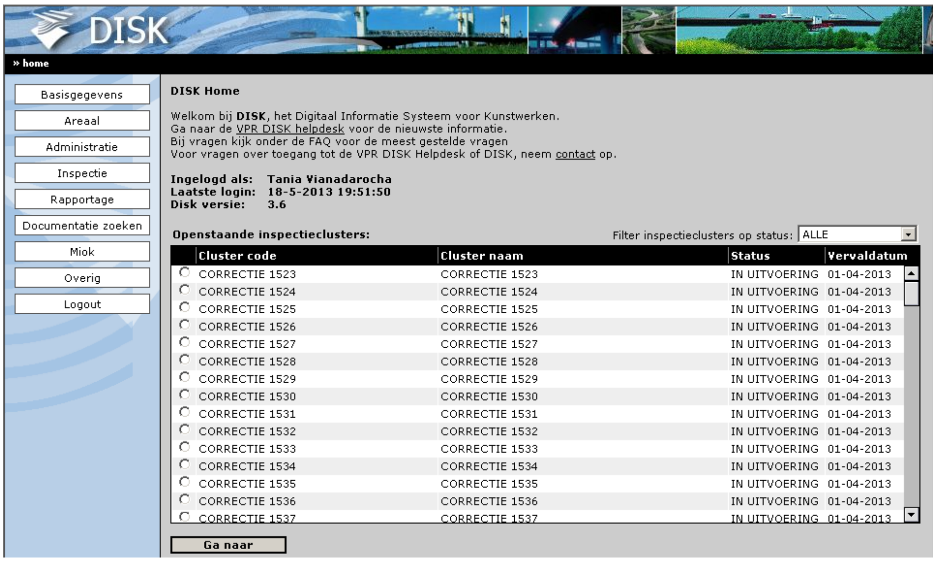


**Figure 5 – DISK Structure Menu. Presentation screen (left side column) [extracted from DISK database].**

**Table 3 – DISK structure menu. Category content and actions allowed.**

| Categories in DISK | Category content | Actions allowed |
|---|---|---|
| Basic data | *Basic Object Data* is presented in DISK per categories (1, 2 or 3)[3]. Data is organized in categories because in DISK they come from different sources or tables. Users may have limited access to some of these categories. | (2) Add<br>(4) Modify |
| Decomposition | Data regarding Management Objects and its parts are decomposed and characterized. | All actions are allowed (1) to (4) |
| Administrative | Inspections are clustered and planned. | All actions are allowed (1) to (4) |
| Inspection | Inspections are maintained, inspection instructions can be changed (if necessary), and inspection results are registered/ stored. | All actions are allowed (1) to (4) |
| Reporting | Inspection instructions and object reports are recorded. Reports are accessed according to the authorized user. | (1) Read<br>(2) Add<br>(4) Modify |
| MIOK | Maintenance Plans with maintenance measures (including last execution year and respective costs) are presented individually or per cluster. These data is generated as inspection data is recorded. | (1) Read<br>(2) Add |
| Search Documents | Management Object documents can be searched. | *Supporting function for the user.* |
| Area filter and modify requirements data | Management Objects and its parts can be changed by an authorized user. | (4) Modify |
| Communication | The documentation on the VPR DISK helpdesk contains several documents, such as: new letters or other sort of communication data. All users have access to these data through an option in the main DISK menu. | (1) Read |
| Disk Management | *For database management.* | *Supporting function for the helpdesk.* |
| Logout | - | - |
| Help | Users support. | (1) Read |

In ***Appendix A1*** is presented the structure menu of DISK [30.].

3

- Category 1: Fixed tables or selected tables. Data coming from various parts of applications (eg. environment, water way, condition).
- Category 2: "Complex" data containing one or more relationships with data already stored (eg. material, damage type, IH Part risk).
- Category 3: Fixed or linked tables. (eg. object type or design specifications).

### 2.3.2. Reporting capabilities.

DISK also generates *immediate* reports (graphical and tabular), which takes place in its extension MIOK. This depends on the criteria that the user selects. For example, object condition level, is one criteria used to analyze the (expected) budget needed in a specific network, within a specific time frame. *(Figure 6)*

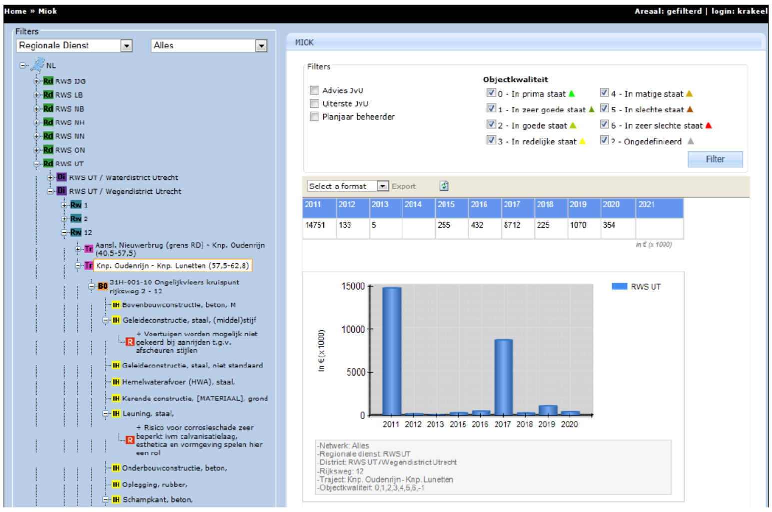


**Figure 6 – Example of a report generated in MIOK [extracted from DISK database].**

### 2.3.3. Mode of data entry and web access.

DISK is accessed through an internet browser[4]. However, the access to the data platform is limited. Data can only be stored in DISK through a local workstation integrated in the network managed by *Rijkswaterstaat*. The user must have:

- an account to log on the local network of the central RWS, and
- an account to log on the system DISK/ MIOK.

If the workstation is not part of the local network, then a connection to this network is needed. This can be done through a *Remote Access Service* which in turn makes use of a SSL VPN *(Secure Sockets Layer Virtual Private Network)* connection. By using an internet browser and using a SSL protocol, a secure connection over the Internet can be made with a SSL VPN network component in *Rijkswaterstaat.* The user needs also a pin code, a password, and a *Token* device (which generates a random code to access to the RWS network and to the DISK database). The support to access DISK is given through an helpdesk service available in *Rijkswaterstaat*. Users can access the database through the DISK website:

### 2.3.4. Resume of IT system information.

The next table resumes DISK IT system information, as defined by IABMAS [11].

**Table 4 – Resume. DISK IT system.[11.]**

| | Name | DISK/ MIOK |
|---|---|---|
| IT data | **Aspect** | **Description** |
| | Platform | Microsoft SQL 2008 |
| | Architecture | Client, Application Server, Database (three tiers) |
| | Data collection capabilities | Data is entered manually in a desk top computer |
| | Reporting capabilities | Reports, graphical and tabular |
| | Web access | Yes |

[4] http://nwr-ipvw-dsk001.ad.rws.nl/intranet/productie/disk/index.asp?id=1

### 2.4. Usage information.

In this label, the use of data collected and stored in DISK is described. *Rijkswaterstaat* makes use of data stored in DISK to assess network condition, and to define maintenance measures and respective costs to keep *their* networks in a predefined condition level. This includes data for maintenance programming through optimization and prioritization of maintenance activities in a network level. Data in DISK does not seem to be used for other purposes, such as for setting performance standards per object level, or for matching funding sources, also per object level. However, these *usage* needs will be assessed in detail under the scope of the second research question of this research project.

The next table resumes DISK usage information, as defined by IABMAS [11.].

**Table 5 – Resume. DISK data usage. [11.]**

| Name | | DISK/ MIOK |
|---|---|---|
| Usage information | **Aspect** | **Description** |
| | For budget preparation | Yes, costs are fed into the network planning system |
| | For setting of performance standards (e.g. target average condition states) | The structure quality index *(see assessment inspection on structure level)* is used as a KPI on network level. |
| | For matching funding sources | Not in the system. Matching funding sources is a feature of the network planning system (RUPS). |
| | For managing special (overweight) transports (e.g. granting permits to cross) | Basic data like design class and results of assessments on capability for overweight transport is in the system. Operations for special transports are treated in another system using this data . |
| | Additional | - |

### 2.5. Operational information.

The category *operational information* gives details about the way data is stored and collected in DISK. In addition, it also describes the *quality criteria* (or rules) established by *Rijkswaterstaat* to give access or to use this database.

#### 2.5.1. Data collection.

Data collected and stored in DISK can be accessed by different users, upon approval given by *Rijkswaterstaat* (via DISK helpdesk). Object *inventory data* can be performed by Administrators (central and/ or regional), or by authorised users (e.g. designers or inspection teams). Inspection planning and clustering is (directly) performed in DISK also by Administrators. *Inspection and intervention data* are exclusively collected and stored by inspectors, which services are usually outsourced to private organizations. However, intervention planning and maintenance programming (preformed at a network level) is done through other systems (i.e. external do DISK). Usually, these activities are performed by the central Administrator. Data regarding intervention and planning is usually exclusive to *internal* use (i.e. to support internal decision-making processes). These processes are analysed in Chapter 4.

#### 2.5.2. Quality assurance.

**Certification and education for external users.**

DISK users (including inspection agencies) need to be certified to access the database. This permit is achieved after attending a one-day course provided by *Rijkswaterstaat,* and after obtaining the respective approval. The training includes the request to perform a *pilot inspection*, where one test inspection must be completed in DISK. When the object is assigned, the inspector being trained must gain knowledge about data assessment, including the procedures to fill in a *Maintenance Plan*. This plan is defined on the basis of risk-based measures and other values. The *pilot inspection* is then mailed to the DISK helpdesk team for acceptance, which is responsible to emit the certification to the user. If the inspection performed does not meet the requirements to obtain a certificate, the applicant must correct the assignment and resubmit it.

**Audits.**

*Rijkswaterstaat* performs audits to inspection agencies within surveillance for establishing contracts. These audits are part of procedures established by *Rijkswaterstaat* for the *Inspection and Advice* process *(see section 4.2).*

**DISK group discussions.**

*Rijkswaterstaat* performs several rounds of consultation with object Administrators and inspection teams. Inspectors gather with object Administrators (on average) three times per year, or four times per year. The goal of these meetings is to discuss: (a) questions and requests from the field (i.e. support of the members of the meeting), and (b) plans for future improvements or upgrades of DISK database. These meetings aim to assess users perceptions that can be useful to improve the database.

### 2.5.3. Resume of operational information.

The next table resumes DISK operational information, as defined by IABMAS [11.].

**Table 6 – Resume. DISK Operational information. [11.]**

| | Name | DISK/ MIOK |
|---|---|---|
| Operational information | **Data collection** | **Description** |
| | Inventory | Owner (Rijkswaterstaat), can be assigned to engineering companies |
| | Inspection/ assessment | Inspectors from engineering companies |
| | Intervention/ planning | No, is treated in network planning system |
| | Additional | The system contains a module for inspection planning |
| | **Quality assurance** | **Description** |
| | Education for inspectors | One-day training for inspectors in the use of the system |
| | Certification for inspectors | Personal certificate based on minimal requirements, i.e. completion of a proof inspection |
| | Education for users | One-day training for other users (not inspectors) in the use of the system. Mandatory for granting access to the system. |
| | Certification for users | No, except for minimal requirements; see inspectors and users |
| | Audits | Audits are performed within surveillance process for inspection contracts |
| | Other | Two user groups exist; inspectors (from private companies) and other users (most Rijkswaterstaat). These groups discuss problems and solutions to improve quality. |

## 2.6. Basic inventory data.

Basic inventory data regards the characterization of objects stored in DISK considering administrative and technical issues, geographic location and reporting aspects. These issues are related to **object area**, and its **decomposition**, as described in the following sections:

### 2.6.1. Object area data and decomposition. Concepts.

Asset management data calls for a network oriented approach [14.]. The same document refers that within *Rijkswaterstaat*, all the business processes have to communicate on the different hierarchical levels, which needs to be done in a **unambiguous** way.

To this end, the physical objects managed by *Rijkswaterstaat* are characterized in DISK according to a standard decomposition. This decomposition is performed with the support of a normative document: NEN 2726-4. The higher hierarchical levels (network down to object) aim to support the communication between the asset manager, and the asset owner. The lower hierarchical levels (object and below) are important for the communication between the asset manager and the service provider, considering inspection and maintenance specifications. The next table presents an example of this categorization:

Table 7 – Hierarchical levels provided by NEN 2767-4 and examples.

| Level | | Examples |
|---|---|---|
| Area data | (1) Main system | Highways network |
| | (2) System | Ring road system Amsterdam |
| | (3) System part | Highway between interchanges A and B |
| | (4) Object | Bridge, tunnel and road section |
| Decomposition | (5) Element | Piers, bearings and pavement |
| | (6) Building component | Top layer, expansion joint seal |

Objects are translated to DISK objects in two categories *(Table 7)*: (1) **area data***,* which includes the object categorization in terms of *Complex*, *Management Object*, and *Object Parts*, and (2) **decomposition**, which includes object data needed for *Maintenance Elements (IH part)*, or *Inspection Components (IS part) (Figure 7).* Each of these levels are described below:

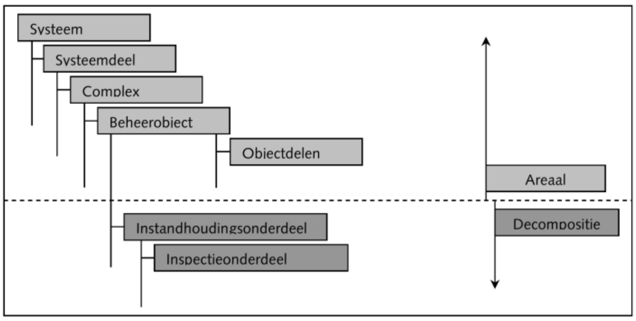


Figure 7 – Area and data decomposition in DISK. [27.]

### a. Area Data.

#### Level 1. Main system

A main system regards a **network** defined in accordance with the classification provided by the primary processes and by the business model of *Rijkswaterstaat*, which is currently managing three networks:

- HWN: Highway Network
- HVWN: Main Waterways Network
- HWS: Main Water System

#### Level 2. System

The networks managed by *Rijkswaterstaat* are divided into **systems** with underlying system components. Thus, in a system level the networks mentioned above are classified according to a:

- Dry System: Corresponding to a Major Road Network (HWN) is composed by national highways, as these are determined and documented in the *Current Route Profile*, or in the *National Road Database*.
- Wet System: Corresponding to the two water networks (HVWN/ HWS), which are defined by topographical units or rivers, canals, coasts and islands. These waterways are used for commercial and recreational navigation (HVWN). They also include national and international basins (HWS).

### Level 3. System Part

A **system part** is a portion of an highway (just for the dry system), or a portion defined between two nodes. The nodes are divided into adjacent system parts.

- Dry System: A dry system meets the directives provided by BPS *(Beschrijvende Plaatsaanduiding Systematiek).* A system is defined by the passage way, lanes, or by its main roads. *Rijkswaterstaat* makes use of geographic instruments to determine exact nodes, where a dry system must have its limits.
- Wet System: A wet system is defined within the waterways. They are defined by system elements, which are similar to water system parts defined in accordance to the national *Beheerplan Nat*.

An area is defined by **systems** and is decomposed into **systems parts***.* A system part is assumed in DISK as a **Complex**. A **Complex** is a collection of one or more objects assembled in a structured unit.

### Level 4. Management Object

A **Management Object** is a coherent and cohesive set of specific provisions, that is physically present in the area to benefit one or multiple-uses (functions) (i.e. it has a functional property assigned). These functions may be taken over by the subsequent Management Object (e.g. serie or parallel connection of *Management Objects*). A *Management Object* cannot be defined in such a way that its performance is just a combination of *Management Objects*.

An **Object Part** in DISK (formed by parts of a Management Object) is characterized by design specifications (technical or constructive), for example, a technical pump room. Thus, an object part is decomposed according to its functional and technical consistency.

*Rijkswaterstaat* has a fixed list of **Complex** and **Management Objects** stored in DISK, which are not possible to be changed due to its unique definition. The current list of ***Complexes*** and ***Management Objects*** types used by *Rijkswaterstaat* is presented in ***Appendix A2***.

## b. Decomposition.

### Level 5. Element

An **element** can be considered a system, in the sense that it is composed by a number of physical objects that when assembled fulfil a specific function. The definition of *parts* are characterized in terms of materials, form, function and required maintenance. This corresponds to **Maintenance Parts** (IH parts). However, the definition of these parts must follow certain rules. The *opbossen procedures* (i.e. merging similar parts together) of IH parts must met the following criteria:

1. IH parts are listed next to each other under the same parent level;
2. IH parts must have the same function as in the object;
3. IH parts ask for the same type of maintenance;
4. IH parts have the same risk profile.

### Level 6. Building unit (component)

A **building element** is physically an identifiable part of an element with a defined (constructive) form, which can be (also) related to specific technical characteristics.

In DISK this corresponds to **Inspection Parts** (IS parts), which are those submitted to inspection activities. The *opbossen procedures* of IS parts must fulfil the following criteria:

1. IS elements are listed next to each other under the same IH parts;
2. IS components must be composed of the same head material;
3. IS parts must be identical in form type;
4. IS elements have the same function in the IH part;
5. IS elements have the same risk profile.

### 2.6.2. *Complex* area data.

A *Complex area* is characterized by the following elements:

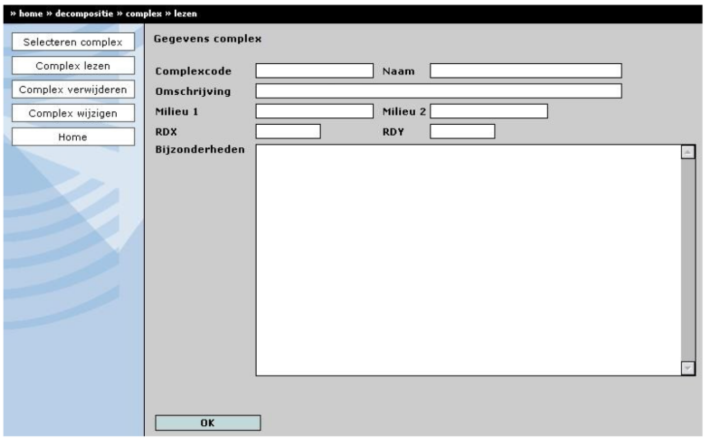


**Figure 8 – *Complex* data in DISK. [42.]**

**Table 8 – *Complex* data in DISK.**

| Categories of *Complex* data | Data content |
|---|---|
| 1. Nomination and references | *Complex* description, including:<br>- Name;<br>- Disk (automatic) codes;<br>- Detailed *Complex* description;<br>- Special features (optional); |
| 2. Complex Environment | Description of the environment in which a Complex is located. This is just applied to locks, aqueducts, tunnels or dams.<br>- Nine (9) categories available in DISK *(eg. aggressive groundwater, chloride, droog, zeemileu, …)* |
| 3. Geographic reference (link to *KERNGIS*) | The Complex is described with reference to *KERNGIS (coordinates X and Y).* Geographic data is also in line with the *Rijksdriehoekscoördinaten* (National Triangulation System). |

### 2.6.3. Maintenance object area data.

A *Management Object* is characterized by the following elements:

**Table 9 – *Management Object* data in DISK.**

| Categories of *Management Object* data | Data content |
|---|---|
| 1. Nomination and references | *Management Object* description, including:<br>- Name (if the object is *wet* it is defined according to National Waterways File);<br>- Disk (automatic) codes;<br>- Detailed *Management Object* description;<br>- Object type and object part. |

| Categories of *Management Object* data | Data content |
|---|---|
| 2. Management property | Description of the responsible parties, including:<br>- Administrator responsible;<br>- Name of the authority as the owner may be addressed;<br>- Management area (eg. RWS/ RPC North East);<br>- Province;<br>- Municipality;<br>- Debtor service (defined in accordance to Current Route Profile). |
| 3. Physical Nature | Data regarding the nature object is located, including:<br>- Physical nature: dry or wet, |
| 4. Network | Data regarding the network where the object is located, including:<br>- Highways network (dry), or<br>- Water network (wet) |
| 5. Special Objects (or Features) | Indication if the object is considered *unique* (a list of unique objects is available in DISK; they are assigned special budgets) |
| 6. Geographic reference (link to *KERNGIS*) | The Complex is described with reference to *KERNGIS (coordinates X and Y).* Geographic data is also in line with the *Rijksdriehoekscoördinaten* (National Triangulation System). |
| 7. Geographic properties | This includes details regarding location, such as:<br>- For dry objects:<br>4. Number of highway the object is located (defined according to Current Route Profile);<br>5. Route of highway (defined according to Current Route Profile);<br>6. Traject (defined according to Current Route Profile);<br>7. Hectometrering (defined according to Current Route Profile);<br>8. Relation to road (eg. in RW, over RW or niet RW).<br>- For wet objects:<br>9. Fairway number (defined according to National Waterway File);<br>10. Hectometrering. |
| 8. Design properties | Design details, including:<br>- For dry objects:<br>11. Material and size *(three (3) categories available in DISK: beton klein, beton groot, staal).*<br>- For wet objects:<br>12. Discharge capacity;<br>13. Shipping class (CEMT). |
| 9. Historical data | Historical data, including:<br>- Designer name;<br>- Year of construction;<br>- Year of demolition (if object is not being used). |
| 10. Object use status | Use status of the object, including: *In use* or *not in use.* |
| 11. Data control | *Data accuracy.*<br>If a box is checked, it means that object data is verified and approved by the Administrator. If errors are detected, the checkmark must be removed. The box serves as an indicator for the user to know that data are checked and fixed. |
| 12. Name of inspection families | Description of existent *on-site* permanent facilities used for inspection *(eleven (11) categories available in DISK: eg. borders, deksel, deur, wagen, voetpad,…).* |
| 13. Hazardous substances | Data related to hazardous substances, including:<br>- Substance name;<br>- Description;<br>- Status of the hazardous substance *(five (5) categories available in DISK: asbestos, safe non-destructive, safe non-destructive type A, safe non-destructive type B), and asbestos unsafe);*<br>- Document uploaded in DISK (optional). |
| 14. Culture history | Data related to culture history, including:<br>- Photos;<br>- Status (valuation to CIWW).<br>- Status color (related to object cultural value) – red, orange, yellow or green[5];<br>- Remarks (optional). |

[5]

- Red: objects with legally protected status (monument: national, provincial or municipal).
- Orange: (high) cultural-historical value.
- Yellow: objects themselves do not have high cultural and historical value but deserve attention because of its surrounding them or their related objects.
- Green: objects without cultural or historical values.

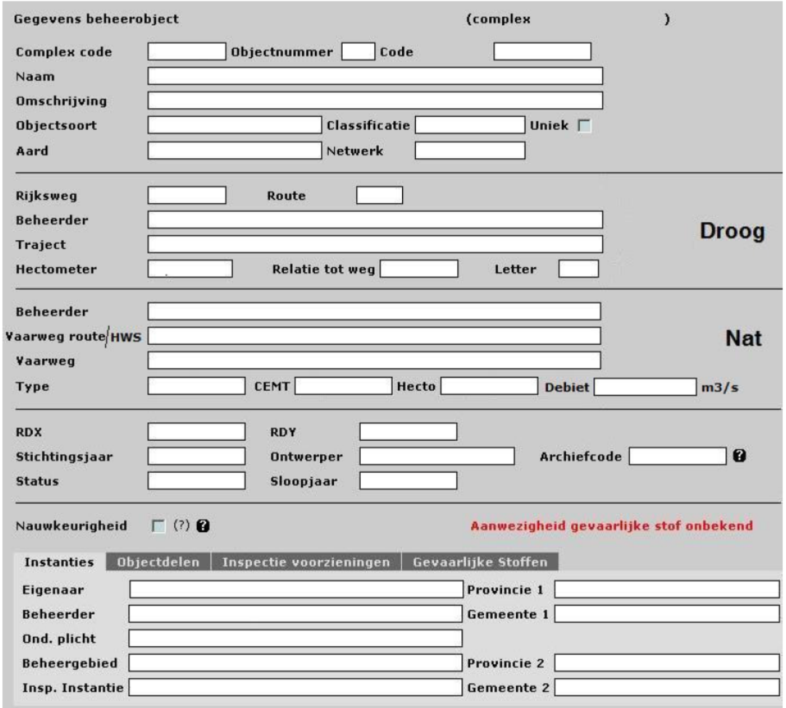


**Figure 9 – *Management Object* data in DISK. [42.]**

### 2.6.4. Object part data

An *object part* is characterized by the following elements:

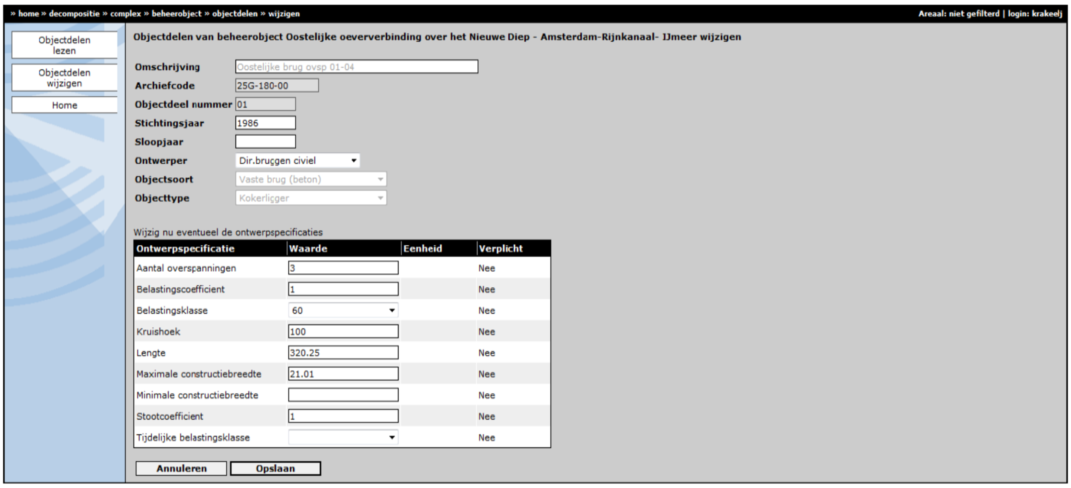


**Figure 10 – *Object part* data in DISK. [43.]**

**Table 10 – *Object part* data in DISK.**

| Categories of *object part* data | Data content |
|---|---|
| 1. Nomination and references | This includes:<br>- Object part description;<br>- Disk (automatic) codes. |
| 2. Historical data | Historical data, including:<br>- Year of construction;<br>- Year of demolition (if object is not being used). |

| Categories of *object part* data | Data content |
|---|---|
| 3. Design properties | Design properties, include:<br>- Technical design units;<br>- Detailed description of object design type;<br>- Object tax class;<br>- Acute angle between axis;<br>- Length of object part;<br>- Width of object part;<br>- Maximum construction width. |

### 2.6.5. Decomposition. Maintenance Parts (IH Parts).

A *Maintenance Part* is characterized by the following elements:

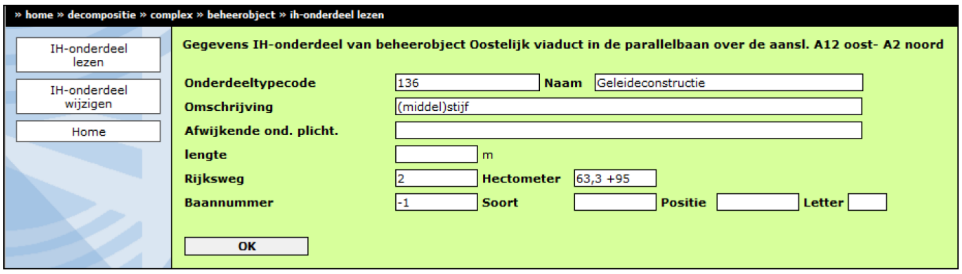


**Figure 11 – *Maintenance Part* data in DISK. [43.]**

**Table 11 – *Management part* data in DISK.**

| Categories of *management part* data | Data content |
|---|---|
| 1. Nomination and references | This includes data related to:<br>- Description and name;<br>- Disk (automatic) codes. |
| 2. Design properties | Design properties, include:<br>- Material of object part;<br>- Technical description of object;<br>- Deviating of addictive duty;<br>- Length. |
| 3. Geographic properties | This includes:<br>- Highway number;<br>- Hectometrering;<br>- Track number;<br>- Highway designation (four (4) categories available in DISK: HR, VB, VW and OJ);<br>- Position of the element (three (3) categories are available in DISK: L, M and R);<br>- Letter (in case of an *exit).* |

### 2.6.6. Decomposition. Inspection Parts (IS Parts).

An *Inspection Part* is characterized by the following elements:

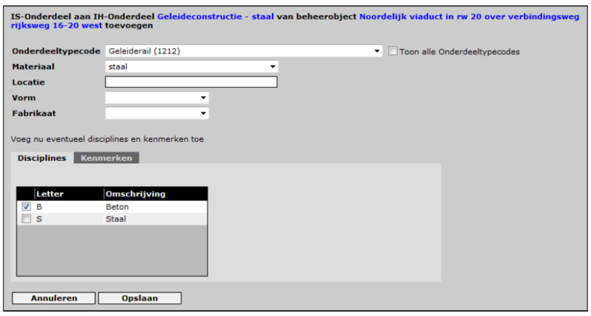


**Figure 12 – *Inspection Part* data in DISK. (I) [43.]**


**Figure 13 – *Inspection Part* data in DISK. (II) [43.]**

**Table 12 – *Inspection Part* data in DISK.**

| Categories of *Inspection Part* data | Data content |
|---|---|
| 1. Nomination and references | This includes data related to:<br>- Name;<br>- Disk (automatic) codes. |
| 2. Design properties | Design properties, include:<br>- Material;<br>- Form;<br>- Place the display on the drawing role;<br>- Name of the manufacturer;<br>- Letter of material;<br>- Technical description;<br>- Characteristics;<br>- Value. |

### 2.6.7. Reports stored.

DISK has also reporting capabilities in the sense that documents generated during the maintenance inspection process are also stored in the system. These reports are related to: (1) area data, (2) inspection per Complex; (3) basic data, (4) inspection and maintenance, (5) inspection per cluster, and (6) data communication with NIS. The access to all (or parts) of these reports depends on the type of authorization given to the user. Figure 14 shows the type of reports that can be stored and accessed in DISK.

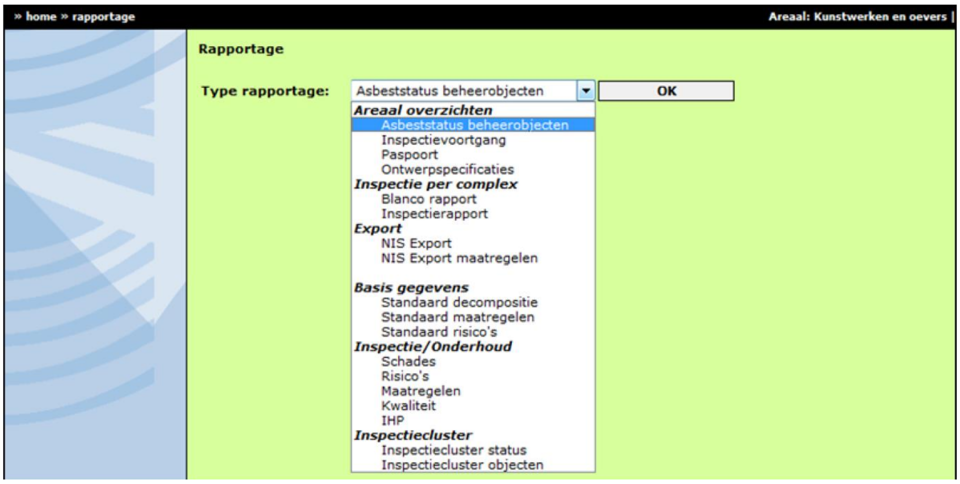


**Figure 14 – DISK Reports Menu [30.]**

In addition to these documents, also inspection drawings and calculations are stored in DISK. Reference documents, newsletters and also contracts can be read through the VPR DISK helpdesk.

### 2.6.8. Inventory data. Resume of IABMAS.

The next table resumes DISK inventory data, as defined by IABMAS [11.].

**Table 13 – Resume. DISK Inventory data. [11.]**

| | Name | | DISK/ MIOK | | | |
|---|---|---|---|---|---|---|
| Inventory data (of principal user) | **Structure types** | **No.** | **Structure types** | **No.** | **Structure types** | **No.** |
| | Bridges | 4180 | Locks and sluices | 147 | Quays | 0 |
| | Culverts | 650 | Retaining Walls | 20 | Piers | 0 |
| | Immersed tunnels | 9 | Storm surge barriers | 4 | Support structures | 0 |
| | Cut and cover tunnel | 6 | Weirs | 10 | Protection structures | 0 |
| | Bored tunnels | 1 | Galleries | 0 | | |
| | **Data type** | | **Description** | | | |
| | Construction data | | Reference to archives is included in the system. | | | |
| | Inspection reports | | Most recent data life in system. Inspection reports are uploaded (.pdf). | | | |
| | Intervention history | | Intervention history is contained in uploaded reports<br>(History is not complete). | | | |
| | Location (e.g. 3D coordinates are recorded) | | X Y coordinates and road coordinates (road number, Km-m). GIS application is available. | | | |
| | Loading (e.g. maximum load carrying capacity is stored) | | Design class from construction code is stored. | | | |
| | Use (e.g. number of vehicles per day is stored) | | No. Stored in Network Information System (NIS) that communicates periodically with DISK/ MIOK. | | | |
| | Additional: | | - | | | |

## 2.7. Maintenance inspection data.

In the next sections, data stored in DISK concerning the *Maintenance Inspections* performed by *Rijkswaterstaat* are described. This includes general inspection registration data, and also inspection results data (risk and performance-based criteria, condition and status indicator), as described in the following sections.

### 2.7.1. Maintenance Inspections. Concepts.

**Data collected in Maintenance Inspections.**

Data collected and stored in DISK is just relative to **Maintenance Inspections**[6]. The end result of data collected during a maintenance inspection can be resumed as:

- An update of **object decomposition** (current status data);
- An update of **risk analysis** (regarding safety and operation);
- Object **status indicator**;
- A **maintenance advice** with maintenance measure to tackle risks assessed (defined in consultation with the Administrator);
- An update of the **Maintenance Plan** (technical bandwidth for future action, including economic optimum, and technical extreme moment of intervention) *(In Dutch: Instanhoudingplan - IHP)*.

**Risk and performance-based indicators.**

Usually, the objects stored in DISK are inspected every five years (for wet objects), or every six years (for dry objects). These inspections are performed under a risk-based analysis, where risks are initially pre-determined in a *desk study*, and are then (visually) assessed through inspection activities. A risk is not necessarily related to

[6] As a concept, data from Condition Inspections *(in Dutch: toestandinspecties),* which are performed every two years (per object), is stored in a different database of Rijkswaterstaat: ULTIMO. The management decision supporting this separation is based on different goals and requirements proposed for the inspections, and on the different methodologies used to perform both inspections.
Nevertheless, sometimes (depending on the situation) *Rijkswaterstaat* allows regional services to store the reports of theses inspections in DISK.

an observed damage, but instead it is focused on a ***cause-effect*** analysis regarding a **desired functioning level**. This analysis uses specific performance criteria based on RAMS, and its components SHEEP. RAMSSHEEP is the acronym for *Reliability, Availability, Maintainability, Safety, Security, Health, Environment, Economic and Politics*. According to [34.], *"the analysis is used to the requirements for the complete solution of the problem to be specified and is used to ensure that the underlying causes are solved or that the solutions provide no new problems".* A risk definition is linked to the aspect with more impact.

**Table 14 – Matrix of risk analysis. [29.]**

| | Gevolg | | | |
|---|---|---|---|---|
| **Kans** | **Te overzien** | **Ernstig** | **Zeer ernstig** | **Catastrofaal** |
| Kans van falen is onacceptabel (calamiteit) | 3 - Verhoogd | 4 - Hoog | 5 - Onacceptabel | 5 - Onacceptabel |
| Geaccepteerde faalkans is ver gepasseerd | 3 - Verhoogd | 3 - Verhoogd | 4 - Hoog | 5 - Onacceptabel |
| Geaccepteerde faalkans is gepasseerd | 2 - Beperkt | 3 - Verhoogd | 3 - Verhoogd | 4 - Hoog |
| Hoger dan direct na oplevering, de geaccepteerde faalkans wordt benaderd | 1 - Verwaarloosbaar | 2 - Beperkt | 3 - Verhoogd | 3 - Verhoogd |
| Hoger dan direct na oplevering maar binnen de geaccepteerde faalkans | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar | 2 - Beperkt | 2 - Beperkt |
| Niet hoger dan direct na oplevering | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar |

A risk is assumed by *Rijkswaterstaat* as the result between the probability of occurrence, and a consequence associated *(risk = probability x consequence).* The probability of occurrence is determined considering the first two years after the inspection activity. The size of the effect is also expressed in a qualitative way in a scale that ranges from 1 *(to oversee)* to 4 *(catastrophic)*. The risk level is defined by the inspector and it is procured in a qualitative manner. Risks are ranked in a qualitative scale that goes from 1 *(negligible)* to 5 *(unacceptable).* Table 14 shows this relationship between risk *probability* and *consequence*.

## Condition.

Under the scope of an inspection activity, the **condition** of a Maintenance Object is also analysed. A **condition level** is also determined by the inspector, which can make use of risk standards, as described in *Reference Documents*. These standards are both technical (e.g. *"the crack formation cannot be greater than a certain value"),* and functional (*"meet the required availability")* [29.]. The condition status indicator is also allocated to the object in a qualitative scale that ranges from 0 *(very good condition*) to 6 *(very poor condition).* These indicators can be seen in Table 15.

**Table 15 – Status indicator (condition *vs.* risk). [29.]**

| | Risk Level of Maintenance Object | | | | |
|---|---|---|---|---|---|
| **Condition Level of Maintenance Object** | **1 Negligible** | **2 Limited** | **3 To oversee** | **4 Serious (high)** | **5 Unacceptable** |
| *0. In good condition* | 0 | 0 | 0 | 0 | 0 |
| *1. In very good condition* | 1 | 1 | 1 | 1 | 1 |
| *2. In good order* | 2 | 2 | 2 | 2 | 2 |
| *3. In fair condition. Risk equipped Attn BON/ RBO.* | 3 | 3 | 3 | 3 | 3 |
| *4. In poor condition. Does not meet the RBO.* | 3 | 3 | 4 | 4 | 4 |
| *5. In poor condition. Does not meet the minimum acceptable level.* | 3 | 3 | 5 | 5 | 5 |
| *6. In very poor condition. Disaster; Direct risk Attn meet the required.* | 3 | 3 | 6 | 6 | 6 |

## Status indicator.

DISK classifies the **object quality** based on: (1) its **condition** *(i.e. the extent to which parts of the object meets the standards),* and based on (2) **risks** *(i.e. the implications towards the performance requirements).* The worst quality of an maintenance object is determined through the *worst* object parts (IH Part), which determines the object quality. The object quality is classified in a qualitative way in scale that ranges from 0 *(low risk-good condition)* to 6 *(high risk-bad condition)*, as illustrated in Table 15.

These concepts are complemented with analysis provided in ***Appendix A3.***

### 2.7.2. Inspection register data

Inspectors are responsible to complete inspection data in DISK. Figure 15 and Table 16 give an overview on the type of inspection data stored in DISK.

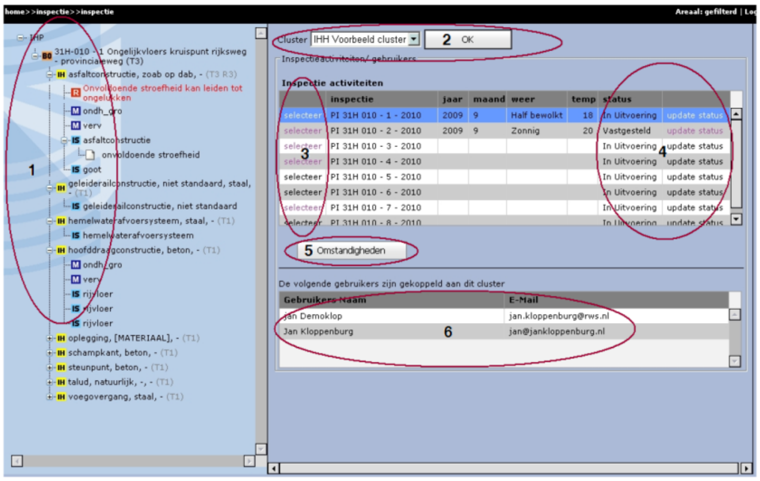


**Figure 15 – Inspection register data in DISK. [27.]**

**Table 16 – *Inspection register* data in DISK.**

| ***Inspection register* data** | **Data content** |
|---|---|
| 1. Object tree<br>*(the tree follows the decomposition defined for object area data)* | Aspects of registration inspection are shown.<br>This includes Management Object code, a letter T with a number and a letter R with a number. The T regards the assigned condition level. The R stands for the assigned risk level, just when risks are registered with an IH component.<br>- Risk description: a risk under a IH component;<br>- Name of the measure: a measure under a IH component;<br>- Name of an inspection unit: an IS element that hangs on a IH part;<br>- Indication of damage with damage type: a damage depends on a IH component. |
| 2. Cluster elective | *For users eligible to access multiple clusters* |
| 3. Inspection activity | Details of inspection activities |
| 4. Status update | “in progress” or “completed” |
| 5. Circumstances of inspection described | Details of the circumstances of inspections. This includes:<br>- Inspection year;<br>- Inspection month;<br>- Weather;<br>- Temperature. |
| 6. Data employees | Staff authorized to access the current cluster. |

### 2.7.3. Inspection results data.

The results of an inspection activity are stored in DISK in four categories: **(1) risks, (2) measures, (3) condition,** and **(4) damage**, as it follows.

#### 1. Risks

For each maintenance component (IH Part), the inspector must characterize the risk identified. To this end, he/she may consider the standard list of risks existent in DISK *(see Chapter 3)*. This means that the inspector must select one of the options available. The inspector can also specify a non-standard risk, if he/she considers that the standard does not apply to the situation. All of these fields are mandatory. *(Figure 16)*

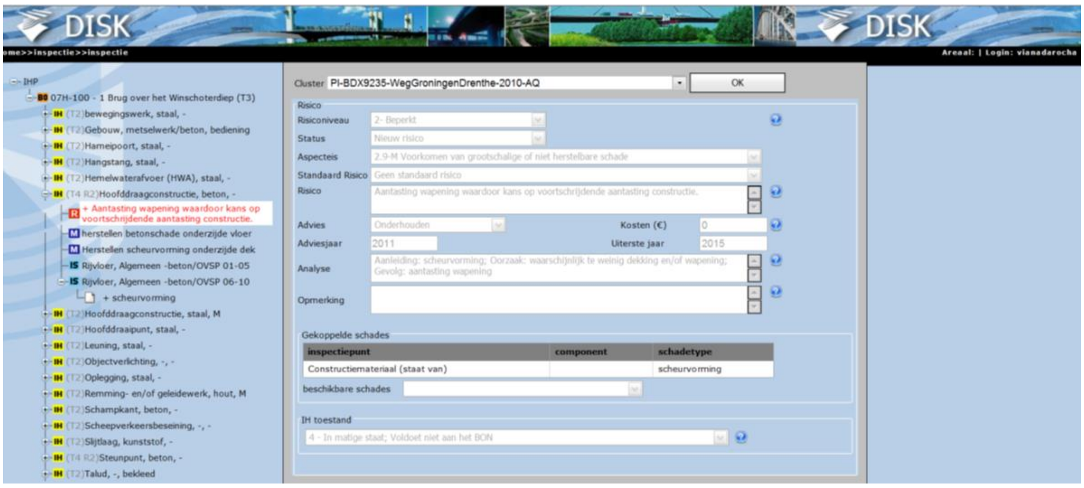


**Figure 16 – *Risk register* data in DISK. [27.]**

**Table 17 – *Risk register* data in DISK.**

| Risk register data | Data content |
|---|---|
| 1. Risk level | Qualitative scale (1 to 5) (Table 15) |
| 2. Risk status | *New* or *existent* risk |
| 3. Aspect | Aspect of RAMSSHEEP criteria that affects risk *(Appendix A3)* |
| 4. Standard risk | Selection of predefined risk stored in DISK and presented to the user in the form of a list. This list is based on risks detailed on *Reference Documents.* |
| 5. Risk description | Description of risk by the inspector. |
| 6. Advice | Predefined list of actions to tackle the risk. |
| 7. Advice year | Advised year to implement maintenance measure. |
| 8. Analysis | Description of risk by the inspector. |
| 9. Description | Description of the advice suggested. |
| 10. Cost | Estimated cost to implement the measure. |
| 11. Extreme year | Latest year to implement the maintenance measure. |
| 12. Maintenance Part condition (IH toestand) | Condition of Maintenance Part (qualitative scale defined from 0 to 6). *(Table 15)* |

## 2. Measures and advice

For each *risk* registered, the inspector must link it to a maintenance measure, in order to mitigate that risk. Similarly to risks, the inspector responsible can use standard measures available in DISK. The inspector can also specify a non-standard measure, if he/she considers that the standard does not applicable to object parts. These data is registered in maintenance measure advice. The elements below characterize the measure and advice data stored in DISK.

**Table 18 – *Measure and measure advice data* in DISK.**

| | Maintenance Measure data | Data content |
|---|---|---|
| A. Measure standard (Maatregel) | | |
| 1 | Standard measure | Standard maintenance measure available in DISK |
| 2 | Measure name | Measure name |
| 3 | Standard measure description | Measure description |
| 4 | Unit | Technical unit for the maintenance measure |
| 5 | Quantity | Quantity of maintenance measure |
| 6 | Standard Interval | Maintenance interval |
| 7 | Latest date for implementation | Latest date to execute the maintenance measure |
| 8 | Standard price per unit | Cost per unit to implement the measure |

| Maintenance Measure data | | Data content |
|---|---|---|
| B. Measure advice (Maatregeladvies) | | |
| 9. | Advice name | Name of maintenance measure |
| 10. | Estimated cost | Cost to implement the maintenance measure (estimated by inspector or standardized) |
| 11. | Optimal date for implementation | *Ideal* date that measure can be implemented |
| 12. | Yearly program | Plan to implement the maintenance measure |
| 13. | Extreme date for implementation | Latest date to execute the maintenance measure |

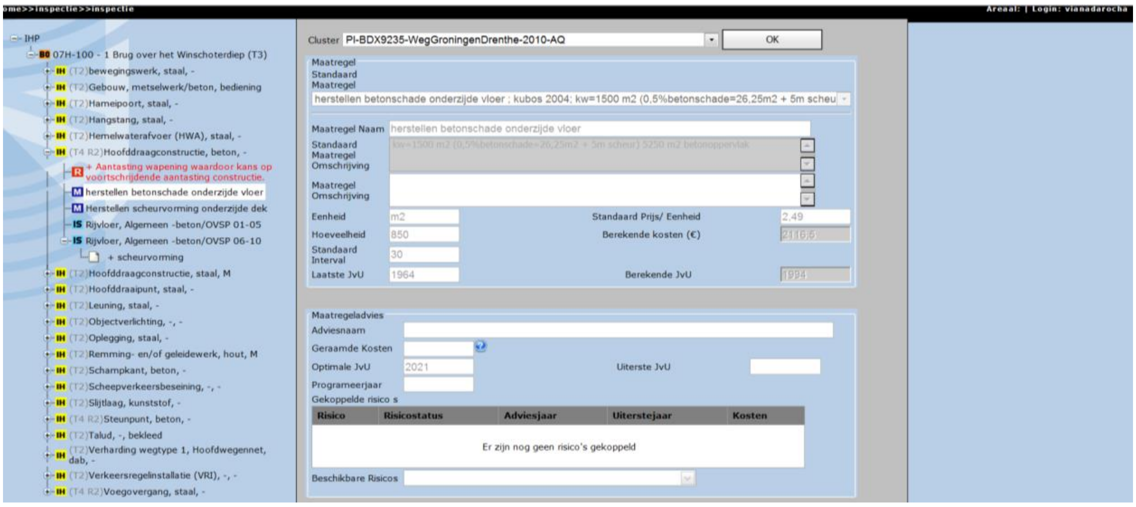


Figure 17 – *Measures and advice register* data in DISK. [27.]

### 3. Condition

After finalizing the risk characterization in DISK, and defining the respective mitigation measures, the Maintenance Part (IH Part) is evaluated regarding **object condition**. Condition states are standard (in DISK), and are defined in a qualitative scale that ranges from 0 *(in Dutch: in prima staat)* to 6 *(in zeerslechtestaat: calamiteit),* as presented in Table 15 and illustrated in Figure 18.

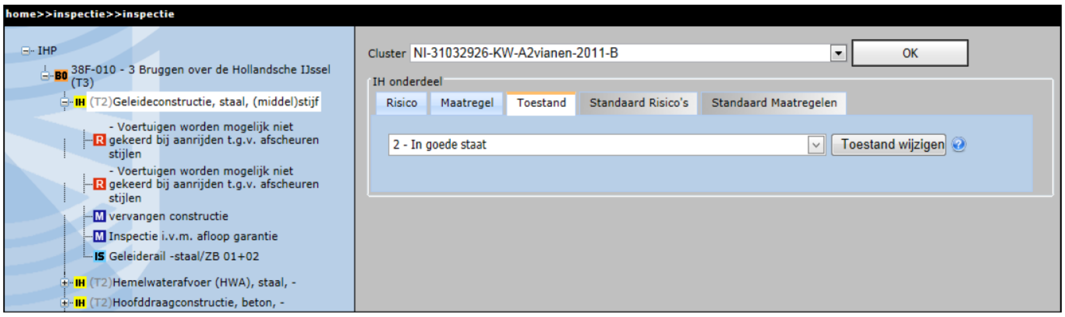


Figure 18 – *Condition* data register in DISK. [30.]

### 4. Damage

Inspection is organized in DISK in a way to minimize free text areas to inspectors. This is also valid for damage registration and its causes, where a limited number of options are given to the user. A *cause-damage* category presents a standard group of causes (for example, design errors, execution errors, degradation, among others). The scope of damage registration is applied to Inspection Part (IS Part).

It is wise to mention that *Inspection Parts* (IS Parts) can be removed, or added before starting the inspection activities. During inspection registration, this is regenerated in order to avoid conflicts with object decomposition *(see Chapter 4).* The figure and table below detail the *damage* data registered in DISK.

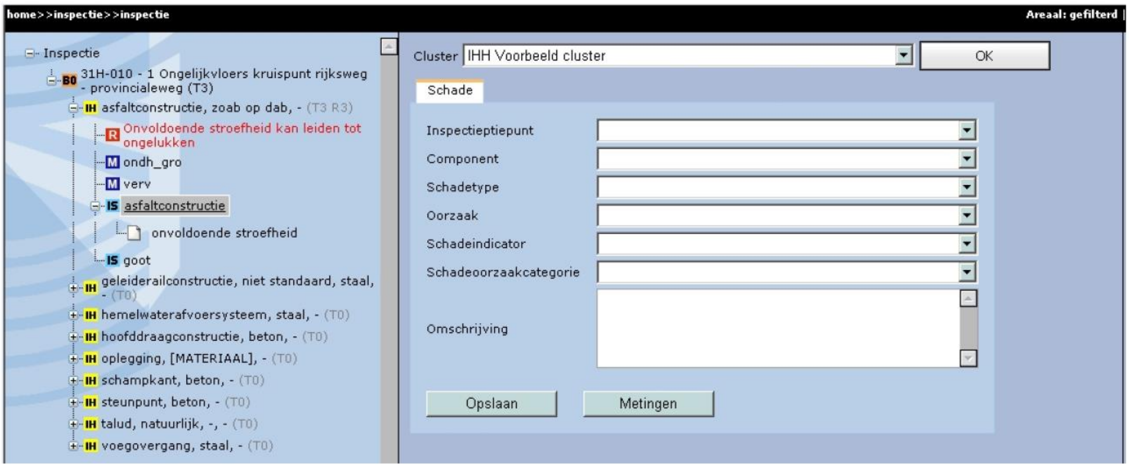


**Figure 19 – *Damage* data registered in DISK [30.]**

**Table 19 – *Damage* data registered in DISK.**

| Measure data | Data content |
|---|---|
| 1. Inspection point | Clarification of the inspection component which damage is observed. |
| 2. Component | Clarification of the respective inspection act. |
| 3. Damage type | Description of the damage. |
| 4. Damage cause | Description of the possible cause of the damage. |
| 5. Damage-indicator | Indication of the degree of damage (qualitative scale that ranges from 1: *no damage* to 6: *direct threat to safety and performance*). |
| 6. Damage cause category | Damage cause category. |
| 7. Description | Brief remarks as important additional information |

### 2.7.4. Inspection data. Resume of IABMAS.

Inspection data characterizes inspection activities regarding (1) the level of data stored (per element or per structure), (2) the type of data handled on element level, and (3) the type of data handled on structure level. However, as it was seen, DISK does not store any data considering (structure) load carrying capacity, or regarding direct assessment of safety. The next table resumes DISK inspection data, as defined by IABMAS [11.].

**Table 20 – Resume. DISK Inspection data. [11.]**

| | Name (version) | DISK/ MIOK |
|---|---|---|
| Inspection data | **Data collection level** | **Description** |
| | Element level (type of inspection on method possible. e.g. visual, non-destructive, destructive) | Visual inspections result in damage descriptions and are basis for condition and risk assessment. Other data can be stored, e.g. test results, plans, photos |
| | Structure level (type of inspection on method possible. e.g. visual, non-destructive, destructive) | Aggregated from element level |
| | **Assessment on element level** | **Description** |
| | Condition (physical) | Elements have a condition rating (0-6) based on visual inspection |
| | Load carrying capacity | Although not standard: risk of insufficient load carrying capacity can be assigned by user |
| | Safety (probability of failure) | Safety is treated as one of the risks, see next item |
| | Risk (probability and consequences of failure) | Risk (RAMS) assessed from damage. The risk level (1-5) is based on possible effects on functions of the structure |

| | Assessment on structure level | Description |
|---|---|---|
| | Condition (physical) | Condition on element level is weighted with risk assigned and aggregated from all elements into a structure quality index. Automated computed value, can be overruled by user. This quality index is a mix of condition and risk. |
| | Load carrying capacity | Although not standard; risk of insufficient load carrying capacity can be assigned by user |
| | Safety (probability of failure) | Although not standard; safety risk aggregated from element level can be assigned by the user |
| | Risk (probability and consequences of failure) | On structure level the quality index is a mix of conditions and risk. See condition. |
| | Additional: | - |

## 2.8. Intervention data.

Data stored in DISK is strongly oriented to characterize **component** and **object**, but it is less focussed on multi-structure condition assessment. Thus, intervention data is defined in DISK only per object type, through an object *Maintenance Plan* (IH Plan), which includes different type of data.

### 2.8.1. Object Maintenance Plan (IHP). Concepts.

Intervention activities are usually defined in DISK per object type, by taking into account the results provided by inspection activities. These interventions are planned in a so called object *Maintenance Plan (IHP).* An object *Maintenance Plan* includes **reference maintenance measures** used per object type. As described in previous sections, the results provided by inspection activities are regularly updated taking into account **object condition**, and **object risks** (determined in line with the RAMSSHEEP performance indicators).

These are necessary conditions to prognosis the risk development identified for the next ten years (i.e. when the risk is no longer acceptable). Sequentially, the inspector must define (or advice) specific maintenance measures to mitigate those risks. In addition, the inspector must indicate the *optimal* time for the implementation of these measures, and also the maximum time period that such measures can be postponed. Similarly to the identification of risks, inspectors can be supported by reference measures, as defined in *Reference Documents* (also called as RBO/OBR).

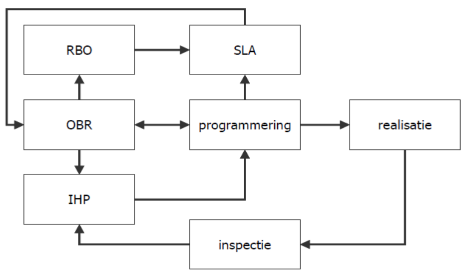


**Figure 20 – Conceptual relationship between internal Asset Management instruments. [32.]**

All of these instructions have a direct effect on the Maintenance Plan, which is also updated by the same inspectors. The basic measures defined in these plans work as a *basic program* to be put into realization. The relationship between these instruments and data provided by regular inspections is schematized in Figure 20.

These data is regularly sent to other databases where *Rijkswaterstaat* defines maintenance programs and prioritizations, usually on a multi-structure level.

### 2.8.2. Object Maintenance Plan data.

The next section describes: (1) the data related to risks and respective mitigation measures, and (2) the data generated in an object *Maintenance Plan* (IH Plan).

### (1) Risks coupled to mitigation measures.

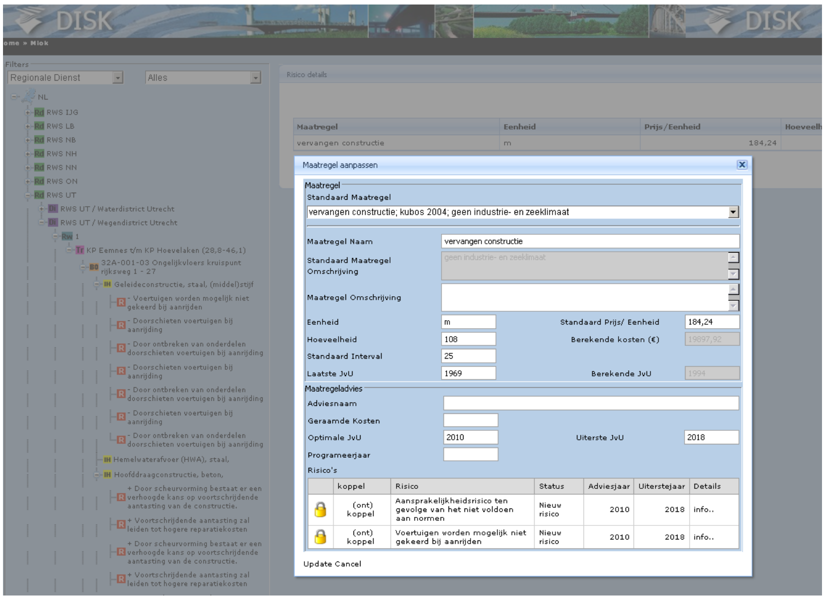


**Figure 21 – Data in DISK. Risk coupled to mitigation measures [extracted from DISK database].**

**Table 21 – Data in DISK. Risk coupled to mitigation measures.**

| Mitigation measures | | Data content |
|---|---|---|
| 1 | Maatregel | Measures (all component data) |
| 2 | Maatregeladvise | Measures advice (all component data) |
| 3 | Gekoppelderisico's | Coupling measure with risk |
| 4 | Status | Risk status |
| 5 | Adviesjaar | Advised year to implement measure |
| 6 | Uiterstjaar | Latest year to implement measure |
| 7 | Kosten | Measure cost |

### (2) Object data in the Maintenance Plan.

The elements below characterize data contained in a regular object Maintenance Plan (IHP).

**Table 22 – Data in DISK. Object Maintenance Plan.**

| Object data in Maintenance Plans. Categories | Data content |
|---|---|
| 1. Complex code | Disk (automatic) codes. |
| 2. Geographic properties | Geographic properties include data as:<br>- Road number<br>- Hectometrering (defined according to Current Route Profile); |
| 3. Management property | Manager/ Administrator |
| 4. Last inspection date. | Data is related to the last set of completed inspections, including:<br>- PI Inspection programming<br>- NI Zero inspection<br>- OVI Delivery inspection |
| 5. Date of modification of inspection date. | It includes:<br>- PI Inspection Programming<br>- NI Zero inspection<br>- OVI Delivery Inspection<br>- Further research OI<br>- GTI Focused Technical Inspection<br>- CO Incidental correction |
| 6. Condition | Object condition level (qualitative scale that ranges from 0 to 6). |

| Object data in Maintenance Plans. Categories | Data content |
|---|---|
| 7. IHP measure | All IH parts are described in the IHPlan with the indication of condition level |
| 8. Execution Year | Suggested year for the implementation of a maintenance measure. |
| 9. Standard intervention years | Standard intervention (years) |
| 10. Cost of intervention standard | Cost to implement the maintenance measure (if this is standard) |
| 11. Year of intervention (advise) | "Optimal year" to implementing the measure. |
| 12. Latest year of intervention (advise) | Latest year to implement maintenance measure |
| 13. Cost of intervention (measure defined) | Cost to implement the maintenance measure (if this is defined by the inspector) |
| 14. Programming year | - |
| 15. Advice (colour scheme) | *(see table 23)* |

**Table 23 – Data in DISK/ MIOK. Meaning of the colours in the IHP [30.]**

| Colour | Field | Definition |
|---|---|---|
| | Advice for implementation period | Plan period without structural risk |
| | Advice to output delay | Plan Year postponed without harming |
| | Advice there | Maintenance program calculated from Reference Documents |
| | Maintenance overdue | Extreme year to implement maintenance is overdue. |
| | Advice missing or expired | Maintenance program calculated is expired |
| | Missing data | - |

### 2.8.3. Intervention data. Resume of IABMAS.

The next table resumes DISK intervention data, as defined by IABMAS [11.].

**Table 24 – Resume. DISK Intervention data. [11.]**

| Name | | DISK/ MIOK |
|---|---|---|
| Intervention data | **Element level** | **Description** |
| | Predefined standard intervention (based on condition state or time) | Standard interventions for reference strategies are predefined. They can be modified by the user. |
| | User defined interventions (based on condition state or time) | User can define custom interventions |
| | **Structure level** | **Description** |
| | Predefined standard intervention (based on condition state or time) | Intervention on element level are presented on structure level in a Maintenance Plan with optimal and ultimate year of execution |
| | User defined interventions (based on condition state or time) | Interventions on element level are presented on structure level in a Maintenance Plan with optimal and ultimate year of execution |
| | **Multiple structures level** | **Description** |
| | Predefined standard intervention (based on condition state or time) | No, is treated in network planning system, together with other object classes, pavements, ITC and such. |
| | User defined interventions (based on condition state or time) | No, is treated in network planning system. |
| | **Costs** | **Description** |
| | Inspection cost | No, except for special inspections |
| | Intervention cost | Yes |
| | Accident costs | No |
| | Traffic delay cost | No |
| | Indirect user costs | No |

These conceptual fundaments are detailed in ***Appendix A3.***

## 2.9. Prediction data.

### 2.9.1. Prediction data. Resume of IABMAS.

In this section, any sort of prediction analysis data stored in DISK is described, concerning: (1) level of deterioration (changes in physical condition and performance indicators), (2) characterization of effects resultant of asset intervention, or improvement, (3) the definition of optimal intervention strategies, and (4) the definition of an intervention program.

Data stored in DISK includes optimal intervention strategies (per object) through the advice provided by inspectors (defined in object *Maintenance Plans*). However, other prediction data does not seem to be procedure to be stored in the database.

The next table resumes DISK prediction data, as defined by IABMAS [11.].

**Table 25 – Resume. DISK Prediction data. [11.]**

| Name | | DISK/ MIOK |
|---|---|---|
| Prediction data | **Aspect** | **Description** |
| | Deterioration, i.e. change in<br>-Physical condition<br>-Performance indicators | Deterioration is not modelled in the system. Offline models are available to correspond with data in the system |
| | Effects of intervention/ Improvement, i.e. change following an intervention in<br>-Physical condition<br>-Performance indicators | Improvements, due to interventions, are not modelled in the system. |
| | Optimal intervention strategies<br>-Period of time analysed<br>-Cost types | Not in the system. Data from the system is used in offline analysis. |
| | Work program<br>-Period of time analysed<br>-Cost types<br>-Budget constraints | - Year +1..- Year +10 (later years are in the system, but incomplete and not used for operational planning)<br>- Costs of interventions assigned on element level<br>- Budget constraints are treated in network planning system |

## 3. OVERVIEW ON DISK DATA SOURCES.

### 3.1. Life cycle based maintenance management.

The management, inspection and maintenance process used by *Rijkswaterstaat*, named as *life cycle based maintenance management* process (LCMM), is based on a set of activities established during the main phases of an object life time. Thus, it is a cyclical process that occurs several times during the object life time.

This LCMM process is composed by six main (sub-)processes, as illustrated in Figure 22. It includes: (1) *Decomposition and Maintenance Plan*, (2) *Inspections and Advice*, (3) *Adjustment of (object) Maintenance Plans*, (4) *Clustering and Optimization,* (5) *Maintenance Execution*, and (6) *End of Service Life*.

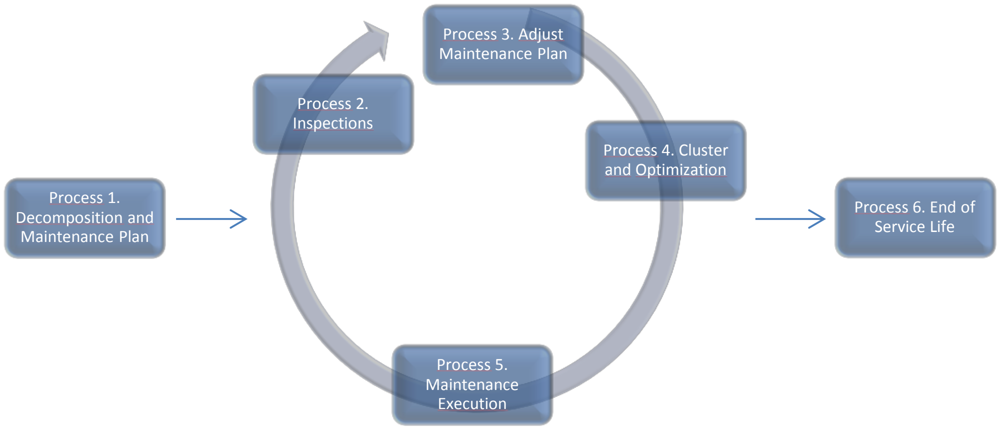


**Figure 22 – Cyclic process management, inspection and maintenance [adapted from 14.].**

These processes are responsible to generate the major part of data that is stored in DISK. It includes data that will have small changes during the object life time *(stable data)*. However, depending on the level of the process, data stored can used to support other processes. DISK also includes data that might need to be adjusted, or updated *(variable data).*

In [27.] an example of the activities that are performed through these processes is given, together with the data generated through them. Therefore, during the design phase, the specific object needs regarding management and maintenance activities are taken into account through a program of requirements. During the execution phase, documentation must describe the specification related to the object execution *("how is the object done")*, and also procedures that can bring to perform specific maintenance activities. Finally, during the usage phase, the object is submitted to a cycle of inspections and maintenance activities, which aim to ensure that the object fulfils the function, and safety for which it is required.

### 3.2. Identification of data sources *to* and *from* DISK.

DISK is an individual management system that is frequently supplied with data provided from difference sources *(Figure 23).*

The processes 1,2 and 3 *(Figure 23, under the green area),* are very object specific, in the sense that data generated or collected through them (and later stored in DISK), are specific to object analysis, which does not depend on other analysis of the network they belong. The processes 4, 5 and 6 *(Figure 23, under the red area)* are more network related considering that data generated is provided by external systems, or analysis. Thus, they have a lower (direct) contribution to generate or update new data in DISK. Nevertheless, these processes **make use** of data stored in DISK to support other processes. The common example is that DISK supplies data to

NIS *(Network Management System),* or to RUPS *(Program for Integrating Maintenance Measures)* on a regular basis.

The *Maintenance Execution* process *(under number 5)*, although being supported by external systems, has a direct connection with process 3 (object *Maintenance Plan*), considering that data supplied in this plan aim to support maintenance activities. During maintenance activities, this plan can be changed, if its content does not fulfils the expectations of the object Administrator.

Finally, when the object reaches the end of its lifespan, the object status is updated in DISK, which leads to generate new data.

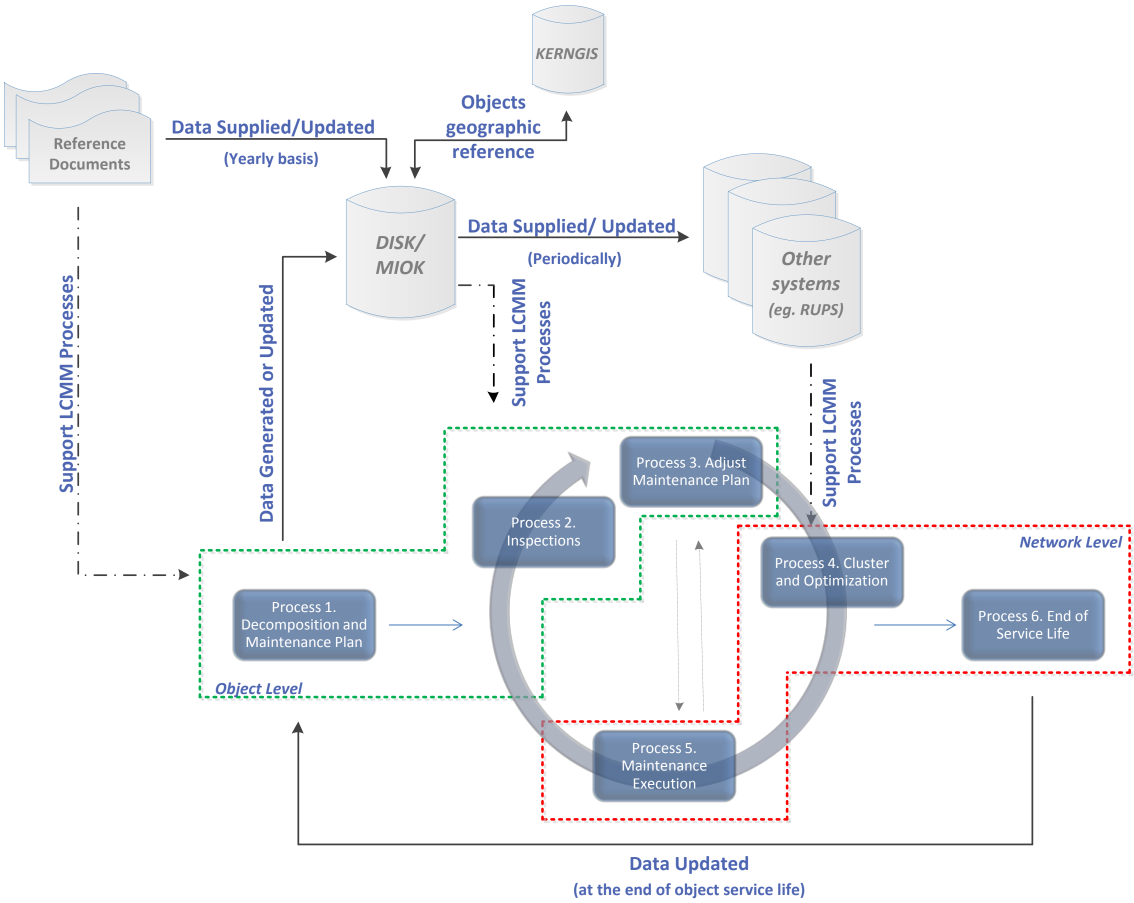


**Figure 23 – Flow of data *to* and *from* DISK.**

Another DISK data source is the set of internal instruments named as ***Reference Documents*** *(also known as BON/ RBO).* These documents are produced by *Rijkswaterstaat* to translate the performance indicators established in agreement with the Dutch Government, named as the Service Level Agreements. The instrument RBO *(Reference Management and Maintenance, since 2011),* or the BON *(Basic Maintenance Level, before 2010)*, include (in outline) the area managed by *Rijkswaterstaat.* They also include a description of the processes needed to be maintained in this area (in a long-term perspective), at the level of policy, defined in accordance with the requirements stated in the national regulations [32.].

In addition, these *Reference Documents* provide standard data related to management measures defined per object type. They include the definition of object **functional requirements**, give an outline of **object maintenance strategies,** and **provide (reference) maintenance advice** to inspection activities (inclusive data object maintenance intervals and unit costs). They also include standard aging behaviour for civil structures (deterioration process), and technical standards about objects under analysis. These documents are updated on a yearly basis.

Part of these standard data is transferred to DISK in a regular yearly basis, as a *reference data* to be selected by the users (namely risks, measures, time of intervention and costs). These documents are also used during the operational activities for inspection and maintenance in order to give respective support to inspection agencies and organizations responsible for maintenance.

KERNGIS is another DISK data source and it establishes a connection between an object, and the respective geographic location. The definition of this geographic reference takes place at the beginning of objects life time, during its characterization in DISK. This data is very stable during the object life time.

## 4. PROCESSES THAT CONTRIBUTE TO GENERATE DATA IN DISK. OBJECT LEVEL.

Object specific data is brought to DISK through the three initial (sub-)processes of this framework: (1) *Decomposition and Maintenance Plan*, (2) *Inspection and Advice*, and (3) Object *Maintenance Plan (Figure 24)*. In the next section, these three processes, and the respective steps, are discussed with emphasis on data collected and stored in DISK.

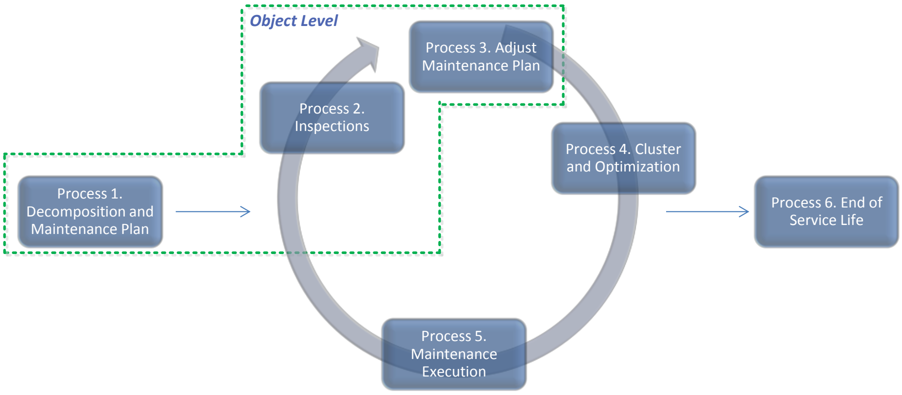


**Figure 24 – Processes that contribute to generate data in DISK (object level).**

### 4.1. Decomposition and Maintenance Plan (Process 1).

#### 4.1.1. Goals of the process and its relationship with DISK.

This process is composed by seven steps (or sub-processes). Each step consists on a set of activities that have interaction with DISK database. Data generated through them can be either new data, or can be updates to the existent data. A *Decomposition and Maintenance Plan* process is initiated with a new object (i.e. new project), and ends with its transference to the usage and maintenance phase *(Figure 25)*.

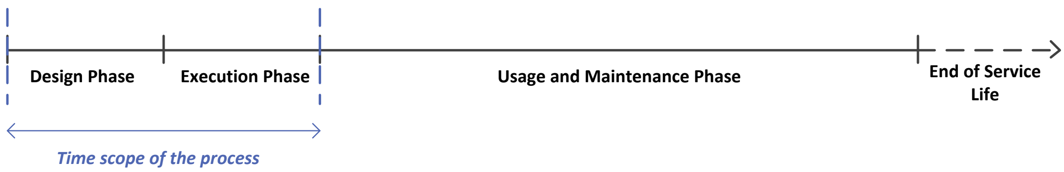


**Figure 25 – Time scope of *Decomposition and Maintenance Plan* process.**

During this process, a *Management Object* is characterized in terms of basic inventory data *(described in section 2.6)*. This includes the specification of object *area data*, and the respective *object decomposition*. Data regarding geographic reference and detailing object technical properties (design) is also defined under this category. Before being transferred to the usage phase, the object is submitted to an inspection, under a process named as *zero-inspection*. The results provided by this initial inspection contribute to determine *reference* object risks, identify *reference* maintenance strategies, and define respective costs. Data generated under these inspection is categorized as inspection data *(described in section 2.7)*.

The end result of this process is a reference *Management and Maintenance Plan* developed to support the (object) Administrator in future management and maintenance activities. This plan, and all the preliminary inspection results, are stored in DISK (inventory data: reports).

For new construction contracts that include maintenance obligation (for example, DBFM contracts), this step ends with the commissioning to perform maintenance activities to a private party. Nevertheless, the object is similarly characterized in DISK. This process takes place at the initial stages of an object service life, and the data generated during this phase has a **relative stable nature** during the object lifetime.

#### 4.1.2. Process steps.

Figure 26 presents the link between the process steps, the activities performed in DISK and the data generated and stored in this database.

**Step 1. Specification of frameworks for Management and Maintenance**

Step 1 takes place during the commission for the design and construction of a new *Management Object.* This is performed by the Central Administrator.

The process starts with the initiative presented by *Rijkswaterstaat* to build a new *Management Object*. This includes the establishment of procurement procedures with market parties to perform the design and construction activities. Some contracts may also include maintenance procedures. In this step the framework(s) to be used for management and maintenance activities are also defined. During these activities, data is not generated in DISK.

**Step 2. Area division**

After the commission to develop a new *Management Object*, step 2 takes place. This step can be either performed by the (object) Administrator, or by the design team.

During this step, the new *Management Object* starts to be characterized in DISK in terms of basic inventory data, particularly defining *area data* (complex and management object). The Administrator submits a request (to DISK helpdesk) to demand authorization to create a new object. Usually, the new object is assigned to an existing *Complex*. After the request for a new *Management Object*, codes for the *Management Object* are generated. If the *Complex* does not exist, then it should be created before the object is further detailed. Then, the new *Management Object* and *Complex* (if needed) are generated in DISK. In here, they are characterized with (DISK) Archive Codes. During this step, an Administrator is assigned to the new *Management Object*, for which he/she is responsible. These data is not expected to be changed. These procedures are detailed in ***Appendix A5.***

**Step 3. Design Analysis for Management and Maintenance**

Step 3 takes place during the design process of a new *Management Object*. Usually, this step is performed by a service provider, which can be either the designer, or a maintenance or inspection experts (which are outsourced to private organizations).

In this step, a design analysis to the object is performed. This regards the verification of specific design requirements, design constraints, and design principles. The analysis covers also the verification of general requirements with respect to inspection, maintainability and substitutability of object components. The purpose of this step is to validate design aspects that can be relevant for future maintenance activities.

These findings are compiled in a report (inventory data) stored in DISK: *Management and Maintenance Design Analysis.* The details of this document are included in ***Appendix A4.***

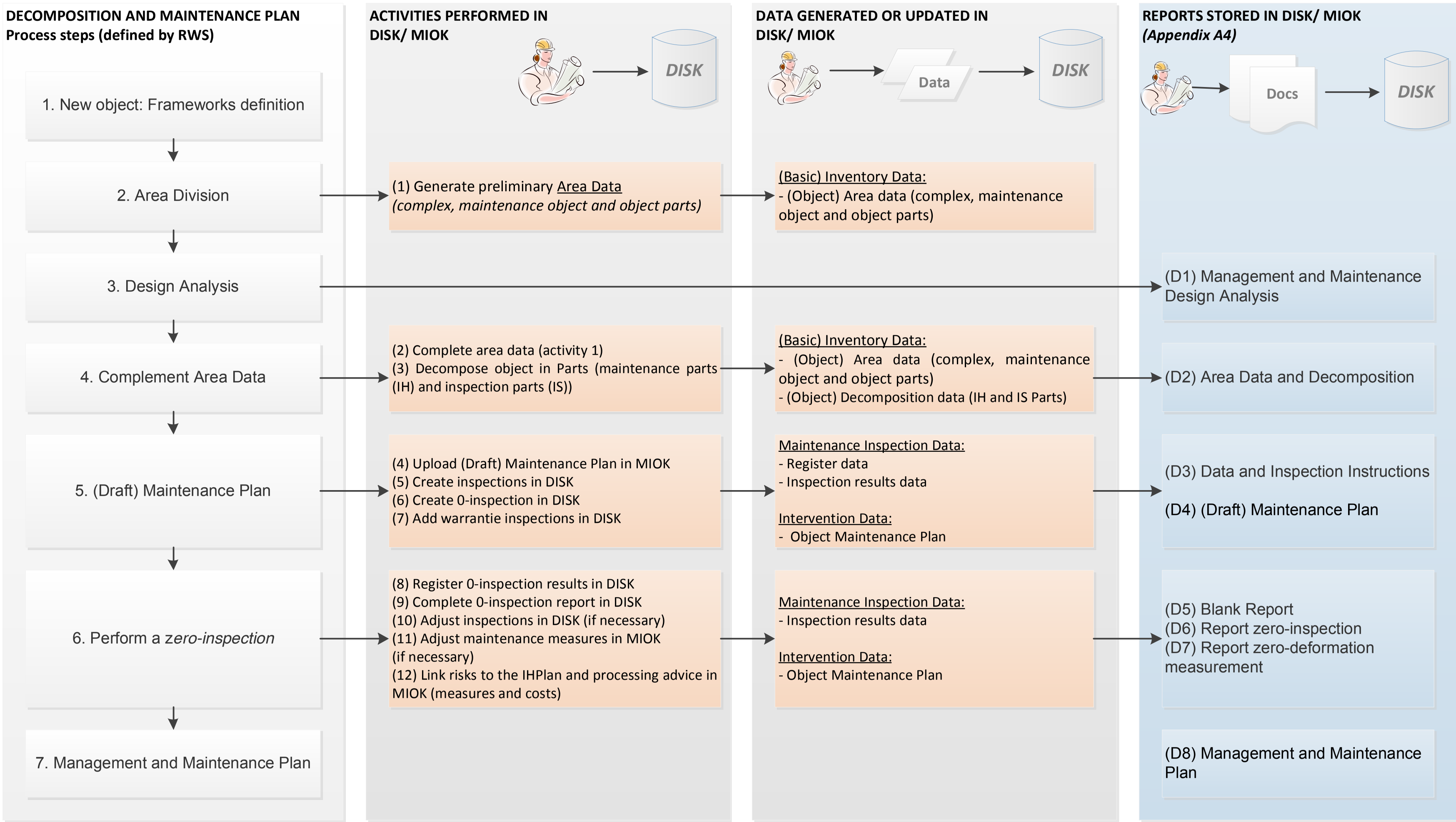


**Figure 26 – Decomposition and Maintenance Plan. Activities performed, data generated and documents stored in DISK/ MIOK (based on [27.])**

### Step 4. Definition and Update of Complementary Areas

Step 4 also takes place during the design of a new *Management Object*. It is performed by a certified inspector, which usually belongs to the design team. However, it can be the case that the Object Administrator let the object be inspected by a certified inspector through a regular maintenance inspection program.

In this step, data already created and stored in DISK (in step 2) is completed or adjusted. This includes *area data,* concerning the *Complex* and the respective *Management Objects* (inventory data).

In addition, the object *decomposition* (inventory data) is initiated and registered in DISK. A decomposition process is related to the division of an object in lower levels. These procedures include the division into *object parts*: its *Elements (or Maintenance Parts)*, and its *Components (or Inspection Parts)*. Thus, object data existent in DISK is now extended. This step is performed according to the procedures presented in ***Appendix A5***.

The end result of this step is the elaboration of a report - *Area Data and Decomposition* - also stored in the database. The details of this report are included in ***Appendix A4.***

### Step 5. Drawing initial Maintenance Plan (IHP)

Step 5 is initiated during the execution phase of a new *Management Object*, and it is performed by a certified inspector (also outsourced for this regard).

The preparation of an object *Maintenance Plan* report includes the definition of a preliminary maintenance strategy to be applied to object parts. The plan presents standard measures to be used for maintenance activities. The goal of this document is to support the Administrator to plan the respective object inspection and maintenance activities.

During this step, several activities take place in DISK, under the category of inspection data. This includes the preparation and the register of the so called *zero-inspection* (see step 6).

In this step main two reports are produced: *Data and Inspection Instructions,* and the first draft of a *Maintenance Plan.* The details of these documents are presented in ***Appendix A4.***

### Step 6. Perform a *zero-inspection*

Step 6 is performed after the execution of a new *Maintenance Object* (immediately before being transferred to the usage phase). Similarly to the previous step, these activities are performed by a certified inspector.

A *zero-inspection* is an initial inspection performed to objects before being transferred to its usage and maintenance phase. This inspection aims to create a baseline for future inspection activities. In these activities, possible object damages are accessed, and the respective (structural) measurements are performed. Eventual damages found are linked to risks, which are also (pre-) determined in this step. Once the inspection activities are concluded, these risks are linked to mitigation measures. Data generated in DISK regards the inspection data (results).

To support these activities, inspectors make use of internal *Reference Documents* (namely OBR/ RBO). The measures defined are detailed in the (draft) *Maintenance Plan* (IHP) created on step 5.

These initial inspection activities generate a set of reports that are stored in DISK. These documents are: (i) a *Blank report*, (ii) a *Report zero-inspection*, and (iii) a *Report zero-deformation measurements*. The details of these documents are included in ***Appendix A4.***

### Step 7. Drawing Management and Maintenance Plan

Step 7 takes place after the execution of a new *Maintenance Object* (immediately before being transferred to the usage phase), and right after the *zero-inspection* being performed. It is also performed by a certified inspector.

A complete *Maintenance Plan* must be completed after the object conclusion (intervention data). It compiles the data gathered during the previous steps of this process, and forms the basis for planning and programming future object maintenance activities. This report, *Management and Maintenance Plan,* and also the drawings used for inspections are stored in DISK. The details of this document are also presented in ***Appendix A4.***

## 4.2. Inspections and Advice (Process 2) and Update Maintenance Plan (Process 3).

### 4.2.1. Goals of the processes and their relationship with DISK.

Internal procedures in *Rijkswaterstaat* combine the *Inspection and Advice* process (number 2), and the *Maintenance Plan* process (number 3) *(Figure 27)*. These processes are integrated in a singular *nine step* process develop for this purpose, named as *Programming Inspection and Maintenance Analysis.*

Usually, these steps are performed between an inspection agency specifically outsourced for this purposes, and the (central and object) Administrator. In this section, data that is generated (or updated) through this process is analysed.

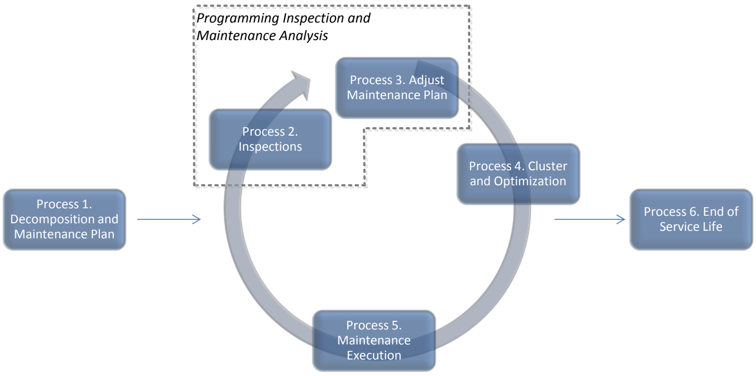


**Figure 27 – Combination of *Inspection Process* and *Updating Maintenance Plan* (based on [27.])**

The inspection results (inspection data) stored in DISK are just related to Maintenance Inspections, which are generally performed every five years (for wet objects), or every six years (for dry objects). The main result of a maintenance inspection is a long term advice (for a ten year perspective), which is defined by the inspector responsible for the inspection. This advice is based on economic optimum principles, and on a defined timeframe to implement the maintenance, as described in section 2.8. These considerations are recorded in a updated (object) *Maintenance Plan* (intervention data).

This cyclical process takes place several times during the object service life which means that data collected has a **variable nature**. *(Figure 28)*

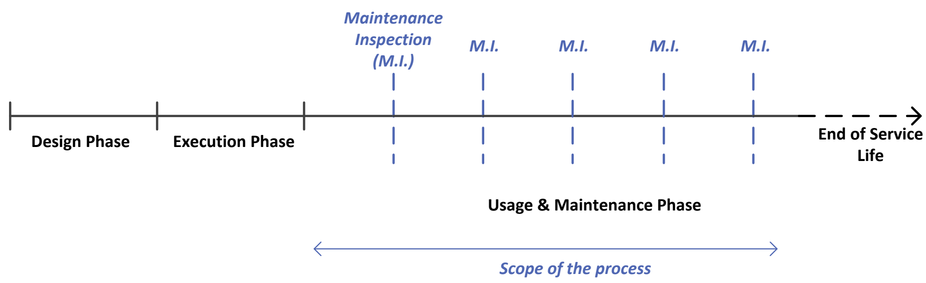


**Figure 28 – Time scope of *Programming Inspection and Maintenance Analysis* process.**

### 4.2.3. Programming inspection and maintenance analysis.

An inspection process takes place through <u>nine process steps</u> (0 to 8) that are organized in three different phases (A to C). Similarly to the *Decomposition and Maintenance Plan* process, each step consists on a set of activities or procedures, that also contribute to generate data in DISK. Figure 30 presents the link between the process steps, the activities performed in DISK and data generated from them. The reports stored in the database are the result of those activities.

#### Phase A. Assignment to the inspection organization and general preparation of the works.

The purposes of the first phase is to prepare an object inspection. The end result of this phase is a project *Quality Plan,* which needs to be accepted by the (Area) Administrator before the beginning of any inspection activities. Phase A of this process includes the <u>preparation scope</u> (step 0), the <u>preparation</u> (step 1), and the <u>intake interviews</u> with area manager (step 2).

#### <u>Step 0. Preparation scope (pre-contractual).</u>

The *preparation* step involves procurement activities. This is based on specific audits performed to the (candidate) inspection agency. During this step, *Rijkswaterstaat* analyzes several aspects of the company. The analysis regards, for example project management, planning issues, and financial health. The outcome of this process is a preliminary project *Quality Plan* that the inspection agency provides to the Administrator. In the meantime, and based on data stored in DISK, *Rijkswaterstaat* creates inspection clusters (or object packages) to be inspected by the candidate <u>(inspection data: registration)</u>. Each package addressed to an inspection company contains around 500 objects. Nevertheless, these contractual procedures will just be concluded at the end of step 2.

In addition, internal procedures take place to give permit to the agency candidate to access *their* inspection cluster, previously created in DISK by *Rijkswaterstaat*. *(Figure 29)*

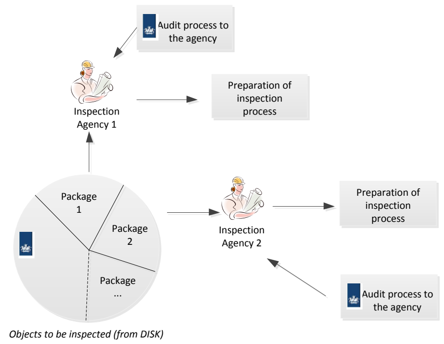


**Figure 29 – Scheme with the preparation of inspection packages.**

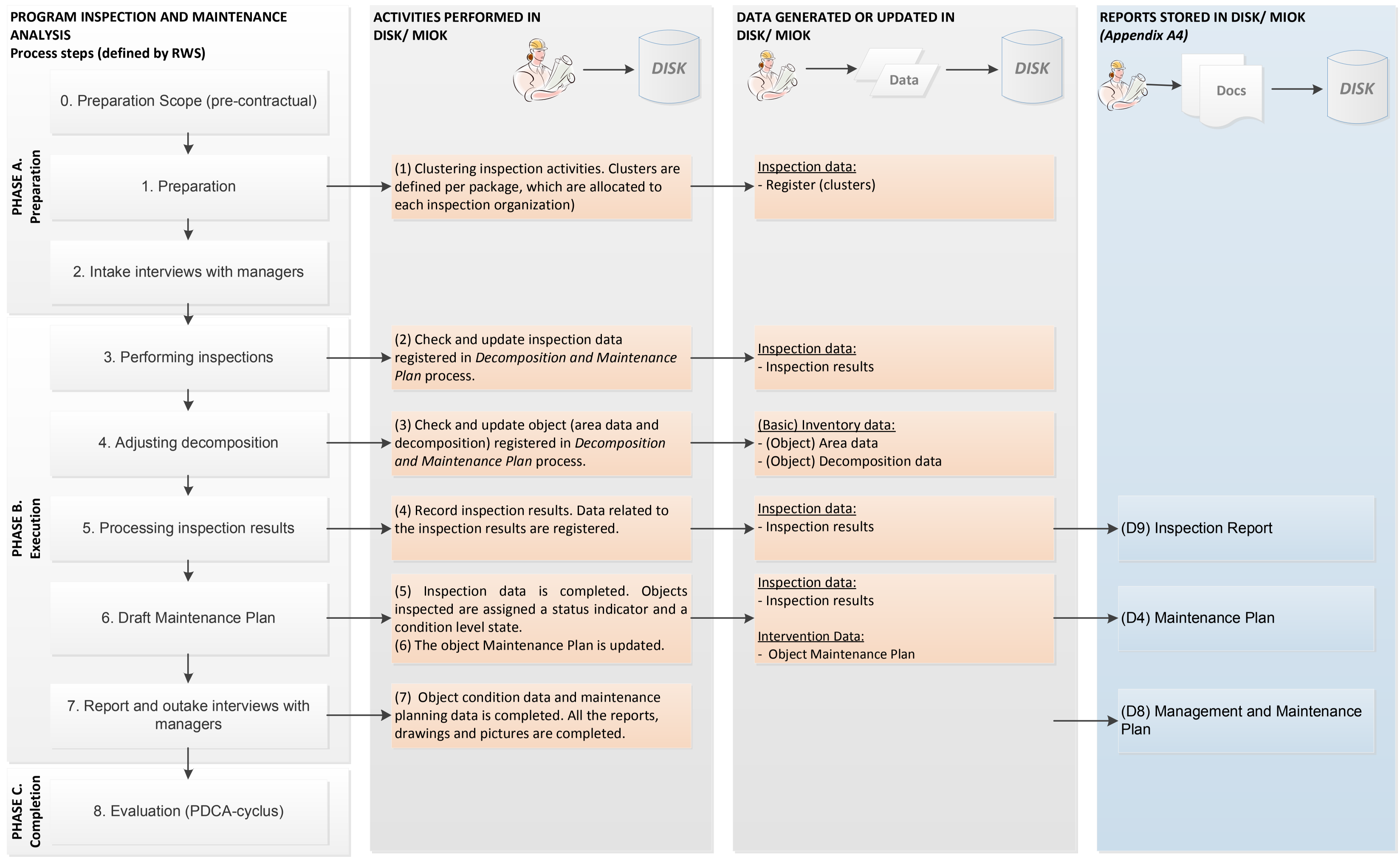


**Figure 30 – Programming Inspection and Maintenance Analysis. Activities performed, data generated and documents stored in DISK/ MIOK (based on [27.])**

## Step 1. Preparation.

*Inspection Plan*

In this step, the inspection company prepares the procedures to initiate the intake interviews with the (Area) Administrator. To this end, the company prepares a comprehensive plan containing inspection details of all objects to be inspected (i.e. objects included in the package procured). This plan works as an extension of the preliminary project *Quality Plan*, and it is a mean to establish communication with the Administrator regarding the upcoming inspection activities. This plan, which is usually submitted two weeks before the intake interviews of step 2, includes [43.]: (1) proposed method for inspection; (2) description of the personal to be employed; (3) security measures; (4) traffic measures and tools (per item inspected); (5) determination of risks to the object part; (6) detailed planning (schedule) for inspection activities; (7) communication (between parties); and (8) organizational and telephone number of emergency services (client and managers) and project staff. This plan is not stored in DISK.

*Risk analysis*

Each object is submitted to a *preliminary* (or desk based) risk analysis developed by the inspection candidate. The rule is that each object (including those underwater) must be fully inspected, except for the cases that on the basis of a risk analysis, do not need to be inspected. This preliminary risk analysis works as a precondition to not overlook, or to not mislead relevant defects. During this assessment, the inspection agency considers the following (main) aspects [43.]:

- Property history of the object;
- Deferred maintenance;
- Design principles;
- Standards and regulations;
- New laws and regulations and criteria to meet the current known regulations;
- Use tax versus design load;
- Recognized design and execution errors;
- Materials and construction specific aspects;
- Time-dependent aging processes;
- Not damaged related risks;
- Failure analysis;
- Spare parts availability;
- Energy performance;
- Multiple expansion joints and *terre armée* constructions (these are by definition considered risky).

*Prepare the inspections activities in DISK ("clustering")*

Also in this step, the inspector assembles inspection clusters in DISK (inspection data: registration). Each cluster is allocated to an object Administrator. These procedures are detailed in ***Appendix A7.***

## Step 2. Intake interviews with Area Managers.

Based on data provided by step 1, namely through the inspection plan and the risk analysis determined for each object, inspection agencies are interviewed by an (Area) Administrator. During these interviews, it can be assessed whether the initial data that *Rijkswaterstaat* gives to the inspection agency is enough, or if additional details are needed.

The purpose of these interviews is to obtain an overall picture of the coming inspection (including details on the objects to be inspected), before the beginning of any inspection activity. If necessary, the inspection plan (step 1) can be modified before these activities are initiated. Bilateral meetings must be held with the Administrator and the inspection organization. During these meetings several issues are discussed, such as [43.]:

- Further agreements on the detailing planning;
- Verify data demand management;
- Specific object risks (for example, environment, use,…);
- Agreements, permits and or exemptions;
- Agreements if someone is joining the inspectors;
- Keys of the future manager with the object;
- Consult Maintenance Plan (IHP) for specific data ;
- Consult last inspection;
- Consult state inspection Administrator;
- Agreements on access to property and closed areas;
- Traffic measures;
- Particulars relating M&E plans, namely considering *(eg: reports of NEN 3140 inspection, reports of performed risk assessments, reports of failure analyzes performed, read power to realize maintenance of data systems, date of commissioning of systems, number of operating hours, fault data/ log, changes made to systems, and acknowledge of not solved problems in systems).*

The result of this step is a record of the interview, a final inspection plan (approved), and a current risk analysis (per object), which is registered in DISK (inspection data: results).

### Phase B. Execution

Inspection activities take place after the conclusion of *Preparation Phase (Phase A)*. Then, inspection activities are performed according to the plan defined during that preliminary phase. The end result of an inspection process is an updated object *Maintenance Plan*. Phase B includes the inspection (step 3), the verification of object decomposition (step 4), the record of inspection results (step 5), the analysis of these results (step 6), and the results report (step 7).

#### Step 3. Run inspections.

An inspection process includes the following activities [43.]:

- Inspection to the entire object (even under water);
    - Only for the specials: inspection of all modular expansion joints components;
- Check and update area data registered in DISK (inventory data);
- Implement the defined inspection instructions stated in the *Management and Maintenance Plan*;
- Record inspection results in the inspection plan (this is not an exact record of the damage, but mainly to allow the positioning of a damage in order to be easily found in the inspection) (inspection data);
- Register photographs with the observed damage scenarios, or other observations. This happens if the inspector considers that a risk is initiate, and on the next 10 years maintenance will be initiated (report).
- (Visually) observe the differences between the situation found in the field, and the assumptions defined in DISK (i.e. object data is assessed through a checklist).
- Created, or modify inspection drawings, only if the initial inspection drawings are missing, or are difficult to read. Drawings with marked damage are added to the inspection in .pdf format (scanned). Then, they must be digitally saved in DISK (report);

- Perform inspection of M&E installations as defined during the intake interviews. Inspections of M&E systems need to be submitted to local inspection, once *'desk study'* analysis is based on data from daily maintenance.

However, inspectors must make sure:

- To not start earlier than the previous process steps are completed.
- To submit a detailed planning concerning the district at least 10 working days prior to the actual inspection.
- To collect the right material and equipment to perform the inspections.
- To have access to the documents needed, such as: the inspection plan, the risk analysis of the object; the old Maintenance Plan (if available); the Blank Inspection Report (from DISK/MIOK) and the inspection drawings.

### Step 4. Change decomposition.

The purposes of this step is to adjust the decomposition registered in DISK (inventory data: decomposition) during the first process *(Decomposition and Maintenance Plan)*. The goal is to obtain the benefit of recording the inspection results, and have the hard data updated. The decomposition registered in DISK is verified (regarding the detected situation), before the registration of inspection results (inspection data: registration). The basic principle is that dry objects have a stable decomposition registered, and the wet objects only have a basic decomposition created (inventory data: decomposition). A standard decomposition must be adopted in accordance with the *Reference Documents*, which support inspectors in these activities.

### Step 5. Record inspection results in DISK/ MIOK.

After stabilizing the object decomposition data (inventory data: decomposition), the inspection results are processed in DISK. In this step the inspection results are recorded, and to each Maintenance Part (IH Part) a state judgment is attributed (inspection data: results). This step includes the following activities [43.]:

- Capture the detected damages (including the identification of *cause*), which in the next 10 years will require maintenance. This is a single assessment of a qualitative condition provided by the inspector impression.
- Capture damage, which needs further research.

### Step 6. Analysis inspection results in DISK / MIOK.

The purpose of this step is to provide insight into risks detected through the inspection, and assign actions to tackle those risks. The result of this step is an updated object *Maintenance Plan* (IHP) .

The defects identified are assigned to inspection component (IS Parts). The inspection results recorded for inspection components (IS parts) are translated into measures for maintenance units (IH parts).

A risk is determined in relation with performance criteria (RAMSSHEEP). For its determination, an analysis to the causal relationships with other damage and object parts (*cause and effect* analysis) is made. Risks can be standard or can be defined by the inspector (inspection data: registration). The same occurs for mitigation measures. In addition, the inspector gives advice years for optimal and extreme implementation years, and also provides a cost estimation for the mitigation measures (intervention data).

**Step 7. Reporting, outtake interviews and acceptance.**

The purposes of this step is to record the results of previous steps. On the basis of inspection results, an outtake interview is performed, where the main inspection findings are discussed (per cluster). These outtake interviews take place after the conclusion of all inspection activities. Practical rules are assigned to these interviews, such as [43.]:

- Ten working days prior to the interview outtake, the inspection reports (digital) are supplied to the Administrator. The outtake interviews will not take place until the approval from the Administrator.
- A week prior to the interview outtake, the inspector must deliver to the project supervisor the main inspection findings;
- Two weeks after the interview outtake, and after any needed adjustments (in DISK and reporting) following the outtake interview, the final reports are submitted to the principal;
- Inspections are accepted into one *.pdf* file (per Management Object), which must be addressed in DISK. The risk management (per object) must be updated as a spreadsheet, or a database file separated from inspection results.

All data (photos, reporting, inspection scanned drawings with damage indication), are developed in a report to be discussed during the outtake interviews. The report should include the following aspects [43.]:

- Inspection (generated) in DISK (inspection data);
- Maintenance Plan (generated) in MIOK (intervention data);
- Definition of potential risks and the preliminary results to be presented to the Administrator (inspection data);
- Relevant inspection drawings indication possible damages (inspection data);
- Relevant pictures of possible damage scenarios (inspection data).

If changes are demanded, they must be proceed in DISK, and a new discussion with the Administrator must take place. This process is repeated until the Administrator approval. After acceptance, the relevant inspection clusters previously assembled by the inspector must be deregistered in DISK.

### Phase C. Completion

The last stage of an inspection process aims to evaluate all the previous steps. This is done according to the PDCA cycle *(plan-do-check-adjust),* and involves the inspection agencies and *Rijkswaterstaat*.

**Step 8. Project evaluation with the client.**

After completion of all inspection clusters in DISK, an inspection evaluation (or consultation) with the central Administrator is initiated. Herein, inspectors can provide suggestions for the improvement of an inspection process. The inspector is responsible for reporting the evaluation of the respective project.

## 5. PROCESSES THAT CONTRIBUTE TO GENERATE DATA IN DISK. NETWORK LEVEL.

The *life cycle based maintenance management* process includes three (sub-)processes, which are focused on a network perspective: (4) cluster and optimization, (5) maintenance execution, and (6) end of service life time *(Figure 31)*. However, not all of these processes contribute to generate (new) data in DISK. In the next sections, the extent of their contribution is analysed.

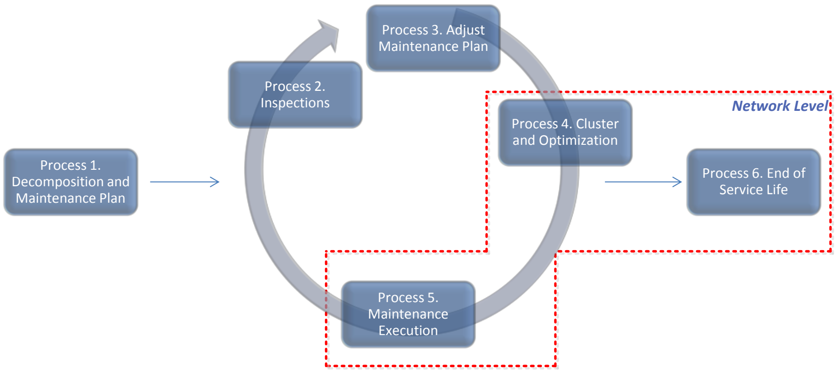


**Figure 31 – Processes that contribute to generate data in DISK (network level oriented).**

### 5.1. Clustering and Optimization (Process 4).

#### 5.1.1. Goals of the processes and their relationship with DISK.

The definition of multiannual programming of maintenance services for the networks managed by *Rijkswaterstaat* combine data provided by several individual data management systems, which includes DISK. The definition of those programs is supported by other systems, as RUPS.

RUPS is an integral program part of the Asset Management process for integrating maintenance measures (clustering) and optimizing maintenance intervention with a network perspective. It aims at combining object maintenance needs (based on *status* indication) with yearly budgets available, and other object class needs *(for example, roads or landscapes) (Figure 32).* The goal is to match needs and funding sources, and transform those needs into implementation projects (including, for example, procurement, capacity planning and registration, and monitoring of operational systems).

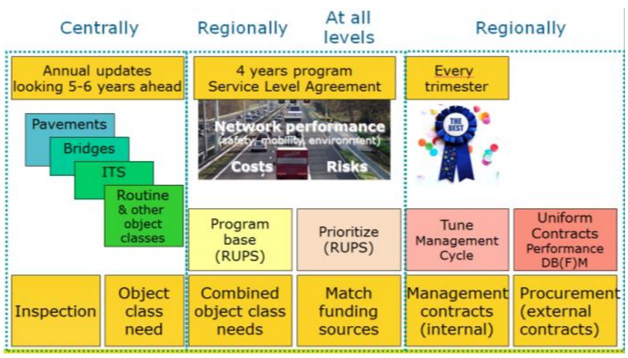


**Figure 32 – Maintenance management programs (adapted from [26.])**

For this integration, *Rijkswaterstaat* links the agreed network performance defined through the *Service Level Agreements*, and the management and maintenance measures needed to achieve such performance. Periodically, DISK sends data to RUPS in order to support activities of programming, prioritizing and planning maintenance. Thus, **during this process new data in DISK is not generated.** This process will be analysed in detail under the scope of the second research question.

## 5.2. Maintenance Execution (Process 5).

### 5.2.1. Goals of the processes and their relationship with DISK.

The aim of the process is to perform the maintenance activities needed per object. This usually happens after instructions provided by external systems, where maintenance activities are planned and programed *(Figure 33)*.

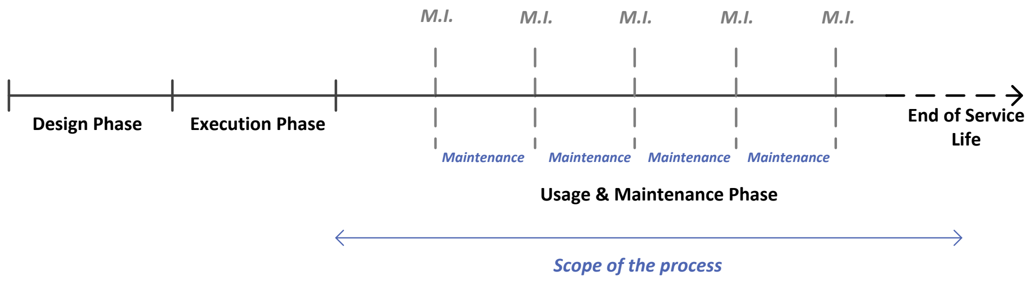


**Figure 33 – Time scope of the process (maintenance execution)**

After maintenance are carried out on an object, the end result can be an updated *Management and Maintenance Plan*. Usually, the updating of a *Maintenance Plan* (process 3) takes place after the *Inspection and Advice* process. However, it can also start after the *Maintenance Execution* process, if the Administrator considers that the current *Maintenance Plan* needs to be adjusted on the basis of a recent intervention *(Figure 34).* This can also require an update on the object decomposition, previously registered in DISK.

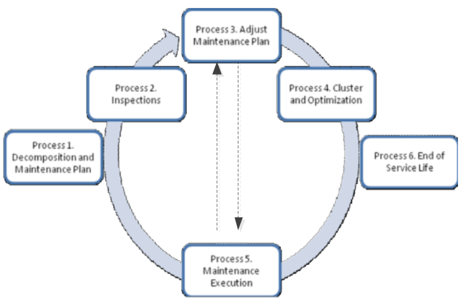


**Figure 34 – Relationship between processes (3 and 5)**

### 5.2.2. Maintenance Execution Process

In *Rijkswaterstaat* the maintenance execution takes place through six main steps. Nevertheless, not all of these steps contribute to generate new data in DISK *(Figure 35).* Step 5 is the only step of this process that may generate new data in DISK (from those described previously).

<u>**Step 5. Zero-inspection**</u>

After a maintenance activity, it is always performed a so called: zero inspection. This zero-inspection has similar characteristics as a regular Maintenance Inspection (performed every 5 or 6 years). The difference is that this inspection is procured under a Maintenance Contract, and not under a regular *Inspection and Advice* process.

Also the results of this inspection <u>(inspection data)</u> are stored in DISK in a similar manner as a Maintenance Inspection[7]. The main difference is that an inspector does not plan the next inspection. During the inspection, the Management Object data can be reviewed and updated <u>(intervention data)</u>. This inspection can bring changes to the object *Maintenance Plan* previously stored in DISK <u>(inventory data: reports)</u>.

In **Appendix A7** the procedures needed to perform a *zero-inspection* after the Maintenance Execution are detailed.

[7] The *zero-inspection* plan is not in line with the plan of a regular Maintenance Inspection, which may bring some incompatibility in terms of time planning. Once the *zero-inspection* has similar characteristics as a regular Maintenance Inspection and there might be between both inspections, *Rijkswaterstaat* is currently discussing ways to combine both inspections in time.

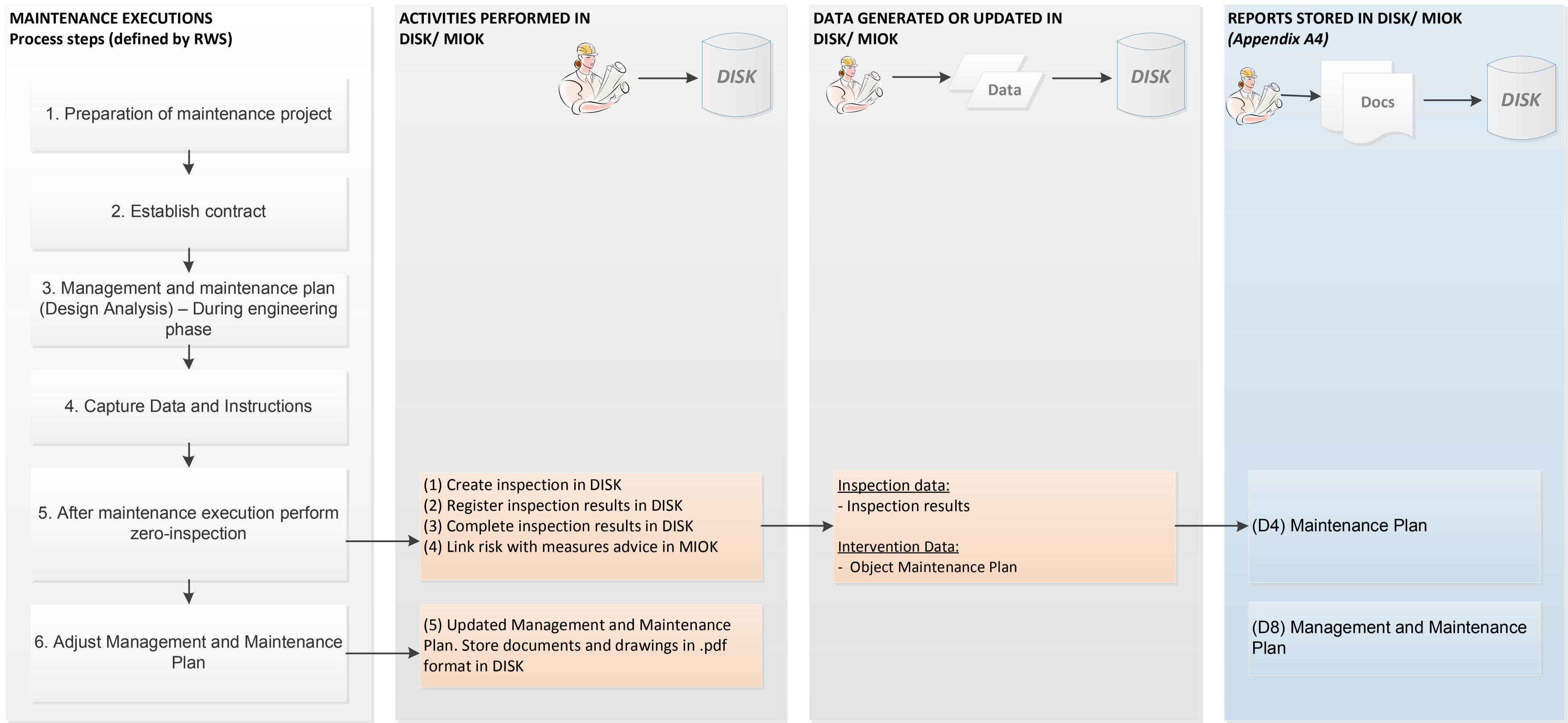


Figure 35 – Maintenance Execution. Activities and data in DISK. (based on [27.])

## 5.3. End of Service Life (Process 6).

### 5.3.1. Goals of the processes and their relationship with DISK.

The aim of this process is to change the status of a *Management Object* so that all the stakeholders know that the object does not exist anymore, or is no longer in use. Thus, at the end of an object life time, the object status must be updated in DISK to *"demolished"* or *"not in use" (Table 26).* The reasons to support this decision can be:

- the *Management Object* achieves the end of technical lifetime (aging);
- the *Management Object* changed the job requirements (new laws and regulations);
- the *Management Object* changed its use (for example, new requirements for traffic);
- the *Management Object* does not fits with the area usage (for example, due to changes in spatial planning). This brings new alternatives to the object:
    - Demolition of the old *Management Object*, and perhaps the replacement of a new one.
    - Exit from the old *Management Object*, and perhaps the development of a new element (not necessarily the replacement)
    - Timely reconstruction or renovation of the old *Management Object*, so that the object fulfils the new user requirements.

In case of a partial demolition, the parts of the object that are being demolished also need to be identified in DISK.

**Table 26 – End of service life time. Activities in DISK.**

| Steps | What? | Who demands? | Who does? |
|---|---|---|---|
| End of life time *(only step)* | Object data stored in DISK changes. The object status changes from "in use" to *"not in use*, or to "demolished", where the object data is put inactive. | • Object Administrator (RWS)<br>• Design/ Build Team (of new object to replace the *inactive*). | • DISK helpdesk procedures. |

## 6. OVERVIEW ON THE PRELIMINARY FINDINGS.

Under the context of the first research question, this document aims to provide a comprehensive analysis on the existent DISK database system, and on the data stored in it. This analysis is performed in two ways: (a.) by assessing the data collected and stored in DISK, and (b.) by understanding the processes that contribute to collect these data. It follows an overview on the main findings in each of these steps:

***a. What is the data collected, stored and managed in the existent data system (DISK)? What are the data characteristics or properties? (data)***

DISK *(Data System Works)* is an individual database used in *Rijkswaterstaat* to store administrative and technical data. These data is related to the condition of infrastructure objects managed by this organization. Generally speaking, DISK can be classified as a *bottom-up* database system with focus on object condition assessment. This means that condition data that is generated and stored in DISK, is mainly focused on object. When combined, DISK data is used by the Administrator to assess networks condition (or parts of it), define and cluster object needs, and prioritize maintenance programs within a budget available.

Based on the DISK theoretical analysis provided by the international organization IABMAS [11.], the database is characterized and the features of data stored in DISK are identified *(Chapter 2)*. By considering its degree of variability, data stored in DISK can be classified in two ways: (1) stable data (inventory data), and (2) variable data (maintenance inspection data and intervention data) *(Figure 36)*.

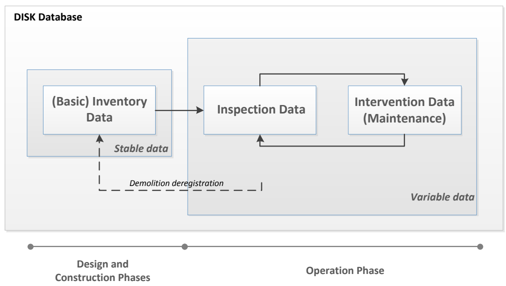


**Figure 36 – Data categorization in DISK (per object).**

In order to use a common language within different levels of the organization, *Rijkswaterstaat* uses a normative document (NEN 2767-4) to categorize the objects they manage. Each object (included in the national highway or water networks) is divided into parts, each part into main components, and each component into elements. During early stages of project development, objects are registered in DISK considering administrative, management, geographical and technical properties (inventory data).

Maintenance objects stored in DISK are regularly submitted to maintenance inspection activities, which results ground the definition of specific mitigation measures, costs and implementation time. To this end, these inspections are based on preliminary object risk-assessment *(desk analysis)*, developed before the inspection activities. These risks are based on a desired state of functioning, established by specific performance indicators (RAMSSHEEP) defined at the national level *(see Appendix A3)*. After the *desk analysis,* these risks are assessed in the field during the inspection activities. The results of these activities ground the inspector classification, which is done in a qualitative way considering risk, damage, and condition level. These results are detailed in DISK under the category of inspection data.

Inspection data forms the basis to define an object *Maintenance Plan*, which is recorded in MIOK (an extension of DISK). Part of these inspection data is already available in DISK through predefined[8] risks, mitigation measures and costs (intervention data). Nevertheless, the inspector has freedom to define these parameters on his/her own. This data is frequently updated according to the inspection and maintenance activities performed (intervention data).

Chapter 2 describes the characteristics of these data categories in detail.

8 *Predefined* means already accessible to the user. This input is provided by *Reference Documents* (also known as RBO/BON).

**b. How and when is the data collected and stored in the existent data system (DISK)? (processes)**

Data stored in DISK is provided from different data sources. For example, *Reference Documents* set standard maintenance measures to link to object risks, and the system *KERNGIS* allows the object to be geographically referenced *(see Chapter 3)*. However, the main data supplier is still the set of six processes that guide *Rijkswaterstaat* to perform management, inspection and maintenance activities *(Life Cycle Maintenance Management process) (Figure 37).*

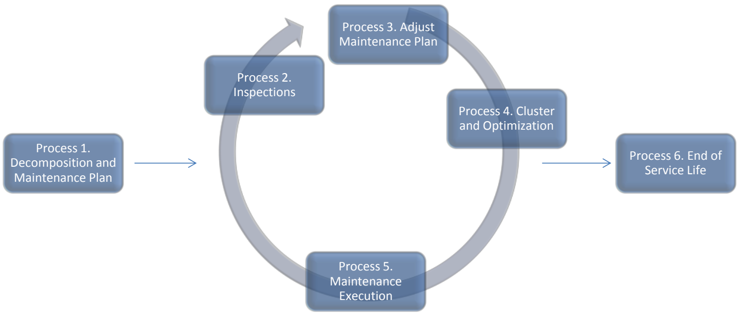


**Figure 37 – Cyclic process management, inspection and maintenance [adapted from 14.].**

The processes of *Decomposition and Maintenance Plan*, the *Inspection and Advice* and the *Maintenance Plan Adjustment* are those from which data is collected on the object level perspective. During the *Decomposition and Maintenance Plan* process, basic registration data is created (inventory data). Nevertheless, part of these data is adjusted under the scope of periodic Maintenance Inspections. The processes of *Inspection and Advice* and the *Maintenance Plan Adjustment* are responsible to generate part of the variable data: inspection data and intervention data, respectively. In these processes, *Rijkswaterstaat* establishes a legal link with an inspection agency, which are usually outsourced to private companies. After being submitted to an audition, these agencies are responsible to assess the condition of the objects that are procured to them. Nevertheless, before the inspections, these inspection agencies must develop detailed assessment on possible risks and must provide *Rijkswaterstaat* with detailed inspection plans. The results of this preliminary analysis are stored in DISK (inspection data), and are later updated on the basis of *in-situ* inspections (inspection data and intervention data) *(see Chapter 4)*.

The remaining processes *(Figure 37, process 4, 5 and 6)* are supported by external databases, or decision supporting systems, and do not have a strong contribution to generate new data in DISK. Nevertheless, some adjustments to existent data (in DISK) may be needed, as for example after a *Maintenance Execution* process *(see Chapter 5)*. Instead, these processes make use of existent data in DISK, created during the three *object level* processes *(Figure 37, processes 1, 2 and 3)*. The extent of the data used from DISK will be analysed under the scope of a second research question.

## 7. FOLLOW-UP WORK.

The next step of this research project is to give answer to the second research (sub-)question defined in the *Research Proposal* previously produced.

The goal of this **research (sub-)question** is to characterize the data needed to support the existent Asset Management decision processes within *Rijkswaterstaat*. The research (sub-)question is structured as it follows:

**2. What are the data requirements to support the decision-making processes within *Rijkswaterstaat*?**

*a. How to characterize the existent Asset Management system in the context of Rijkswaterstaat organization?*

*b. What decision processes are supported by the existent data collected and stored in DISK?*

*c. What is the data needed to support decision-making processes within Rijkswaterstaat? What attributes must these data have?*

Understanding the data requirements to support decision-making processes is a necessary condition to assess the gap between the existent data (in DISK), and the data required (from DISK) to support those processes. The goal is to perform a data *supply-and-demand* analysis and identify potential areas of improvement *(Figure 38)*. This potential can have different sources. For example, it can be identified on the properties of data stored in the DISK system, and/ or can be located on the processes from which the data is collected, and then stored in the database.

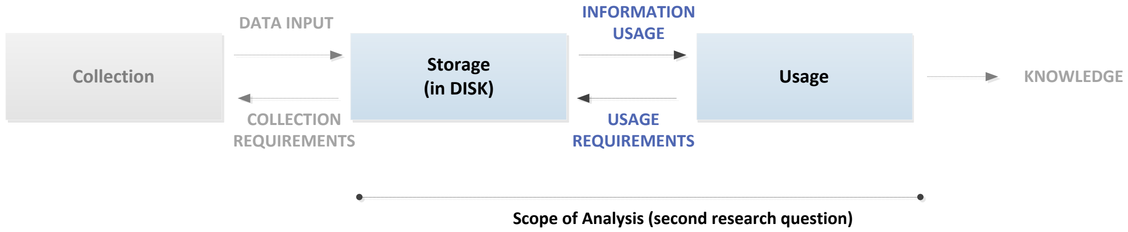


**Figure 38 – Scope of analysis (second research question).**

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# APPENDICES

## List of appendices:

- Appendix A1. DISK Structure Menu. [30.]
- Appendix A2. List of Complexes and maintenance objects in DISK.
- Appendix A3. Conceptual fundaments to perform Maintenance Inspections and advice.
- Appendix A4. Reports generated in DISK.
- Appendix A5. Procedures to introduce object data in DISK.
- Appendix A6. Procedures to cluster inspections in DISK.
- Appendix A7. Procedures to generate zero-inspection in DISK.

The next image structures data categories and functions present in DISK database. Functions provided in MIOK are not presented in this diagram.

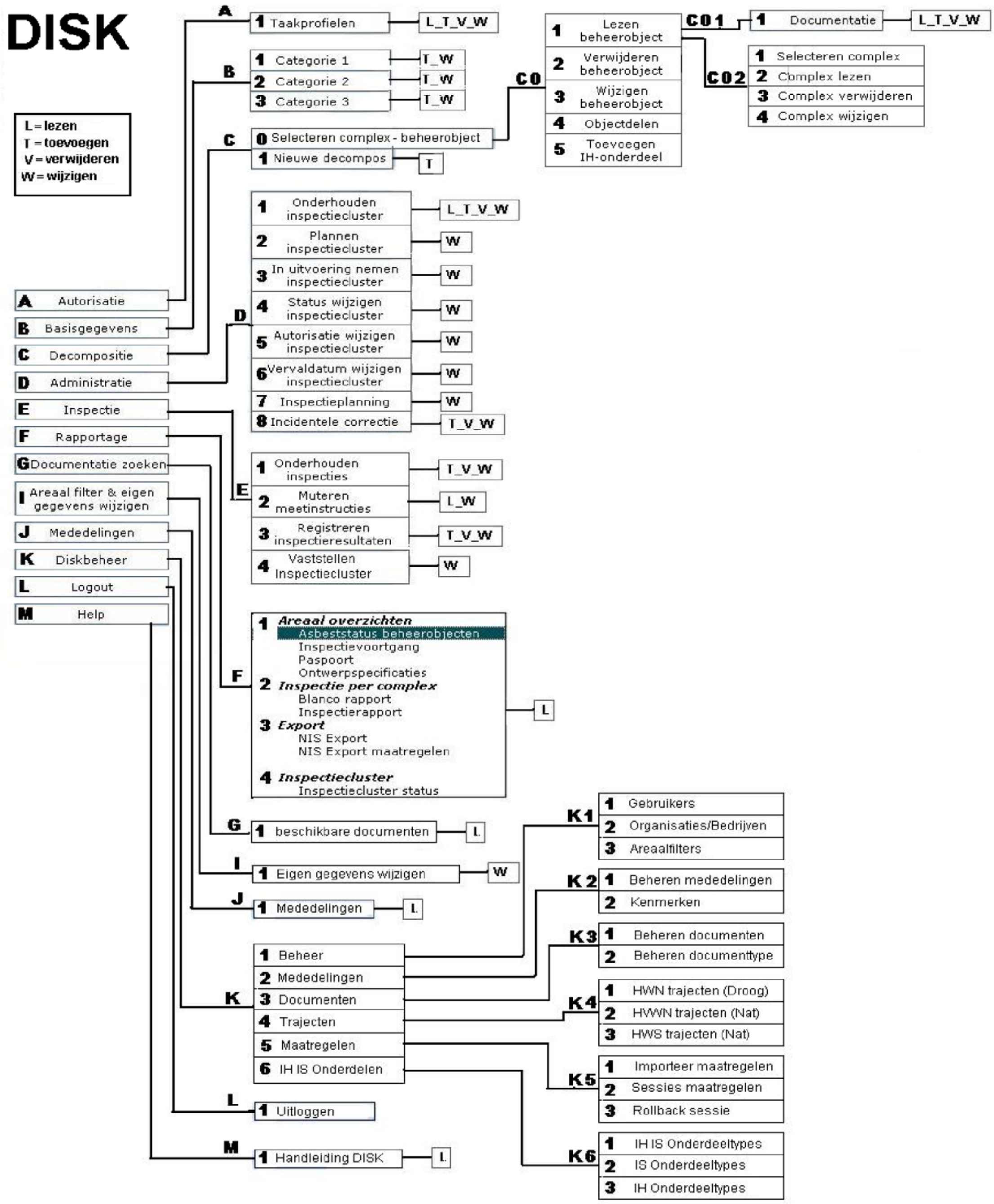



**Figure A1.1 – DISK structure menu. [30.]**

## 1. List of existent *Complexes*.

The following table presents the list of complexes registered in DISK/ MIOK (until December of 2011).

**Table A2.1 – List of *Complexes* established by *Rijkswaterstaat* (December, 2011).**

| Regional Administrator | Complexes | | |
|---|---|---|---|
| RWS IJG | Houtribsluizen | Lorentzsluizen | Ramspolbrug |
| | Ketelbrug | NaviductKrabbersgat | Roggebotsluis |
| | Krabbersgatsluis | Nijkerkersluis | Stevinsluizen |
| RWS LB | Prinses Maxima sluizen | SluisComplex Born | SluisComplex Maasbracht |
| | Sluis/stuwComplex Belfeld | SluisComplex Bosscheveld | SluisComplex St. Andries |
| | Sluis/stuwComplex Borgharen | SluisComplex Heel | SluisComplex Weurt |
| | Sluis/stuwComplex Grave | SluisComplex Heumen | St. Servaasbrug |
| | Sluis/stuwComplex Roermond | SluisComplex Limmel | Stuw Complex Linne |
| | Sluis/stuwComplex Sambeek | SluisComplex Linne | |
| RWS NB | Aarle-Rixtelse brug | Erpsebrug | Sluis 4 |
| | Beeksebrug | Hooydonk | Sluis 5 |
| | Brug Biesthoutakker | Houtens | Sluis 6 |
| | Brug Bosscheweg | Kasterensbrug | Sluis Engelen |
| | Brug Dr. Deelenlaan | Leveroysebrug | Sluis Helmond (DE) |
| | Brug Enschotsestraat | Marksluis | Sluis I |
| | Brug Groenewoud | Niesakkerbrug | Sluis II |
| | Brug Heikantsebaan | Noordervaart (sluis Hulsen) | Sluis III |
| | Brug Heuvel | Orthenbrug | Sluis IV |
| | Brug Holenakker | Sluis 0 | Sluis Panheel |
| | Brug Lijnsheike | Sluis 10 | Sluis Schijndel |
| | Brug Oisterwijksebaan | Sluis 11 | Sluis V |
| | Brug Oranjelaan | Sluis 12 | Stad van Gerwen |
| | Brug Son | Sluis 13 | Trappistenbrug |
| | Brug Waalstraat | Sluis 15 | Amertakbrug |
| | Dungensebrug | Sluis 16 | |
| RWS NH | Aanleginrichting Den Helder | Coenbruggen | Schellingwouderbrug |
| | Aanleginrichting Texel | IJmuiden sluizen | Schinkelbrug |
| | Balgzandbrug | Kaagbruggen | Schipholbruggen |
| | Brug Zijkanaal C | Kooybrug | Vechtbrug |
| | Buitenhuizen | Oranjesluizen | |
| RWS NN | Aanleginr. Harlingen-Terschl. | Aanleginrichting Vlieland | Scharsterrijn |
| | Aanleginr. Harlingen-Vlieland | Eelwerderbrug | Westergobrug |
| | Aanleginrichting Holwerd | Euvelgunnerbrug | Westerwoldsche Aa |
| | Aanleginrichting Lauwersoog | Fonejachtbrug | Zuidbroek (Winschoterdiep) |
| | Aanleginrichting Nes | Julianabrug | Brug over de Ringvaart - Nieuwe Pompsloot |
| | Aanleginrichting Schiermonnikoog | Koningsbrug | Coupure in Dorpstraat Vlieland |
| | Aanleginrichting Terschelling | Kruiswaterbruggen | |
| RWS ON | Amerongen | Hagestein | SluisComplex Hengelo |
| | Driel | Meppelerdiepsluis | Spooldersluis |
| | Eilandbrug | SluisComplex Delden | |
| | Grote Kolksluis | SluisComplex Eefde | |
| RWS UT | Cosijnbrug | Muntsluis | Prs. Irenesluis |
| | Koninginnensluis | Noordersluis | Prs. Marijkesluis |
| | Montfoort | Pr. Bernhardsluis | Waaiersluis Gouda |
| | Muntbrug | Prs. Beatrixsluis | Zuidersluis |
| RWS ZH | Biesboschsluis | Haringvlietbrug | Spijkenisserbrug |

| | | | |
|---|---|---|---|
| | Brug o/d Beneden Merwede | Haringvlietsluizen | Suurhoffbrug |
| | Brug Oude Rijn | Harmsenbrug | van Brienenoord |
| | Brug over de Boven-Merwede | Helsluis | Verkeersbrug Dordrecht |
| | Brug over de Noord | Hollandsche IJssel | Volkeraksluizen |
| | Calandbrug | Ottersluis | Wantijbrug |
| | Giessenbrug | Spieringsluis | Wilhelminasluis |
| | Goereesesluis | | |
| RWS ZL | Bergsediepsluis | Hansweert | Postbrug |
| | Draaibrug Sas van Gent | Krammersluizen | SluizenComplex Terneuzen |
| | Draaibrug Sluiskil | Kreekraksluizen | Vlakebrug |
| | Gemaal Kreekrak | Oosterscheldekering | Zandkreeksluis |
| | Grevelingensluis | | |

## 2. List of existent *Management Objects* types.

The current list of *Management Objects* being used in Rijkswaterstaat is:

**Table A2.2 – Current list of *Management Objects* established by Rijkswaterstaat.**

| Management Object | Code in DISK | Network | Definition | Object classification |
|---|---|---|---|---|
| Aanleginrichting veerpont<br>*(Mooring arrangement ferry)* | KF | Major road | A special equipped place for the construction of ferries. This consists of a main structure (with lifting beam), pontoon and trap. | The entire mooring arrangement is a bank, or an object considered, with bridges, viaducts, lift towers, control houses, trap constructions, roofing and some objects are seen. |
| Afmeervoorziening<br>*(Mooring facility)* | KA | Main waterway | A special object in the water for the construction of marine/ recreational equipped floating, or permanent facility. | The set of structures, which together with a boat/ ship enables to create an object. Here are considered mooring to the various banks or sides a lock as a separate object. |
| Aquaduct<br>*(Aqueduct)* | KQ | Main waterway | Bridge promoting an open water connection (canal or river) on a road, railway line and/ or with a geographical incision site is headed. | The open and closed parts, back constructions, ramps, zinc elements, load roads or building operations of an aqueduct are considered as an object. Viaducts are within a *Complex* if from the box construction are seen as separate objects. |
| Brug Beweegbaar<br>*(Movable bridge)* | KB | Major road | Moveable connection for traffic between two points by water that are separated (river or canal, for example). Movable bridges include a steel main structure and a steel/ wooden trap or surface driven. | The ramps of a movable bridge are part of the movable object. It depends on the number of ramps that are divided into two or more sub-objects. Any cellars of movable bridge are not regarded as separate object (these are partial objects or components). In the event that the bridge is in a lock Complex, and is a fixed part of the door (lifting or doors), this is not regarded as a separated object. |
| Brug Vast<br>*(Fixed bridge)* | KV | Major road | Fixed connection for traffic between two points that are separated by water. A fixed bridge consists of a main structure of concrete and/ or steel. | *(No additions to the general principles)* |
| Coupure<br>(??) | KC | Main water | Construction in a dike body in favour of a connection for traffic, which if closed by sliding and/ or stop logs one damming function. | The entire aperture in a dike body is considered as an object, wherein the number of separate openings does not matter. If carried out in combination with a viaduct, it is treated as a separated object. |
| Duiker, Hevel, Sifon<br>*(Culvert, Siphon)* | KZ | Main water | A closed structure under a road, railway, wharf, or embankment for discharging or intakes of water.<br>Special types of divers:<br>*a. A plunger type, consisting of a bent pipe construction, which water at a given level of the water in the other one is caused to flow*<br>*b. A culvert, composed of a deeper tube. A diver includes walls, roof and floor either tube.* | A diver is considered to be an object if the structures of the different divers are connected to each other. If between the different divers do not constructive connections, they are seen as separate objects. |
| Geluidswering<br>*(Soundproofing)* | KM | Major road | Construction along a road or a railway that aims to reduce noise in the environment, other than the noise barriers on structures, such as bridges or overpass. A noise barrier includes a possible drainage systems and a construction boom. | All the possible noise barriers on different locations within a Complex are considered as separate objects. If a noise barrier is placed on a ground barrier, these are two separate objects.<br>Sound proof construction can be registered in DISK/ MIOK if there is a Maintenance and Inspection Plan for the object. |

| Management Object | Code in DISK | Network | Definition | Object classification |
|---|---|---|---|---|
| Gemaal<br>*(Pumping)* | KG | Main Water | Device to draining a polder or open water, with which the position of the surface is controlled. A pumping station includes a pump unit and a building or buildings. | Pumping stations in basements or underpasses are not for controlling the surface state, and thus form a (main) part of the underpass. |
| Grondkering<br>*(Soilbarrier)* | KL | Major road and major water ways | Artificial boundary, which is the underlying ground body in place. | Within a Complex all the possible ground defences on different locations are considered as separate objects. The difference between a "recesses road" and a ground retaining wall is determined by the single or two sidedness of the ground retaining wall. In combination with a noise barrier are these considered two separate objects. |
| Hoogwaterkering (incl. Stormvloedkeringen)<br>*(High weir, including storm surgebarriers)* | KH | Main water | Construction that uses a (weir) or sliding door lock in case of a water flooding function. | All artwork on the type of KH in the repeated failure function of the Complex do fail, belong to an object. The entire Oosterschelde storm surge barrier is an object, since the failure of a recurring slide the OSK function does fail. |
| Installaties ten behoeve van Complex<br>*(InstalationsforComplexes)* | AI | Major road and major water ways | The set of mechanical and electrical (sub) systems in a Complex, which ensure the functioning of multiple objects in a Complex management. | An installation specifically attributable to an object, it forms an integral part of that object. If there are a plurality of individual objects in a Complex supported, it is considered as a separate object. |
| Kelder<br>*(Cellar)* | KK | Major road and major water ways | A building structure below ground, which is free of other Management Objects. | Basements as formulated in the definition of the object types (detached from other Management Objects), are rare. (Water) cellars under bridges, tunnels, underpasses, etc. are part of the object. |
| Onderdoorgang<br>*(Underpass)* | KP | Major road | A building structure below ground, which is free of other Management Objects. | All closed and open parts (sunken road) which are connected to constructive connection elements an object with one or more sub-objects. If there are over a considerable length is not constructive pieces are located behind each other between two underpasses, this forms two separate objects. Cellars t.b.v of drainage (including pumps) are not considered as a separate object, but some objects or components. |
| Overkluizing | KO | Major road | A closed structure under a road, railway, wharf, embankment, etc. for the protecting and guiding intersecting cables and pipes (gas, water, sewage, electricity, etc.). An *overkluizing* includes a main support structure. | *(No additions to general principles.)* |
| Sluis<br>*(Lock )* | KS | Major road | Through open doors weir, which forms the connection between two waters with an uneven water level or with different water quality. Special types of locks are:<br>*a Schutsluis. A lock which ships can be shaken.*<br>*b. Spui-/uitwateringsluis. A lock that allows excess water to a certain difference in water levels, water is discharged from one water to* the other water. A lock is built from lock heads, drain and sluice gates. | All adjacent chambers are individual objects within a Complex. Two or more chambers located behind each other are seen as an object. If several gullies are present within an, it is the control building as a part of the first (having not most) vortex considered. The general installations for multiple objects within the Complex must be taken as a separate object (KI). |
| Stuw<br>*(Weir)* | KW | Major road | A dam or barrier in a watercourse in order to upstream water to a certain level or to rise to a certain level. A weir is built up from, include a floor and a weir or sliding flap. | All adjacent weirs which a water level reality represent jointly an object. If weirs one behind the other, different water levels and to achieve same Complex, are being considered as separated objects. |

| Management Object | Code in DISK | Network | Definition | Object classification |
|---|---|---|---|---|
| Tunnel | KT | Major road | Artificially engineered, tubular or tubular passage below ground. | All closed and open parts (toerittten, sunken road) which are part of constructive tube / tube form an object. Within the pipe / tube, several passages are created by means of partitions. These can be used as separate passages object part that are defined within the object. |
| Verdiepte weg *(Sunkenroad)* | KY | Major road | An open road structure located below the surface. A sunken road includes other from a superstructure with (retaining) walls and possibly a solar grid. | The entire tank construction is considered as an object, wherein the presence of a boundary between the two carriageways is excluded. If the lanes into two separate floors are being seen as two objects. Basements t.b.v of the drainage (incl. pumps) are not considered as a separate object, but are some objects or components. |
| Viaduct | KE | Major road | A (direct mounted) fixed connection for traffic between two points separated by a road, railway line and/or a soil incision. A viaduct includes a main structure of concrete and/or steel. | There is a further distinction is made in crossovers 'in' or 'on' the road.<br>Viaducts are divided into objects according to the general principles. When a road crosses another road, the viaduct road then belongs to the highway where the joints are in it. The crossovers in the roads (on the intersecting road) are among the main road where you come from a "highway overpass. and exits, any cross overs counted to the road where they are going, or coming off. Viaducts on the road are mostly in managed by third parties. |
| Waterreguleringswerk *(Water regulationwork)* | KR | Main water | A construction for the benefit of the inlets, outlets or passage of water, not being a pumping station or sluice. | *(No additions to general principles.)* |
| VDC | KD | Major Road | Traffic-related frameworks facilities which are information carriers, such as(matrix) signs, drips and cameras to be hanged. Portals and brackets belong to the VDCs. | Each VDC is a separate object (not recorded in DISK/ MIOK). |
| Kunstwerken t.b.v. natuur *(receivers objectsfornature)* | KN | Major road or main water | Specific works serving the migration of flora and fauna. Fish ladders, tunnels and badgers ecoducts are some examples. | *(No additions to general principles)* |

<u>Note:</u>

In 2012 DISK was enlarged with other management objects, rather than just being exclusive to infrastructure objects *(In Dutch: 'kunstwerken')*. This was a request of the former Waterdienst (in Lelystad), and includes: (1) vertical bank/shore and (2) natural friendly bank/shore. These objects were initially put in DISK by converting data from another system (BKN). These objects data have similar properties as a regular *'kunstweren'* object (Complex / Management Object / Object part / Maintenance IH-/ Inspection IS-Part).

## 1. Structure of the appendix.

This appendix analyses the main conceptual fundaments adopted by *Rijkswaterstaat* to perform object *Maintenance Inspections*, in order to determine **object risk** and **condition state**, and to provide **inspection advice**. This comprehensive analysis is organized as it follows:


**Figure A3.1 – Outline of the Appendix A3.**

## 2. Maintenance types performed by *Rijkswaterstaat*.

A *management object* is periodically submitted to **Maintenance Inspections**, where data is collected for the purposes of updating an object **Maintenance Plan** (IHP). Such plan is usually established for a period of ten years. However, *Rijkswaterstaat* complements **Maintenance Inspections** with other **middle term** inspections.

*Rijkswaterstaat* performs three different inspections to the objects that they are responsible: (1.) Regular Inspection *(in Dutch: schouw)*, (2.) Condition Inspection *(in Dutch: toestandsinspectie)*, and (3.) Maintenance Inspection *(in Dutch: instandhoudingsinspectie). (Figure A3.2)*

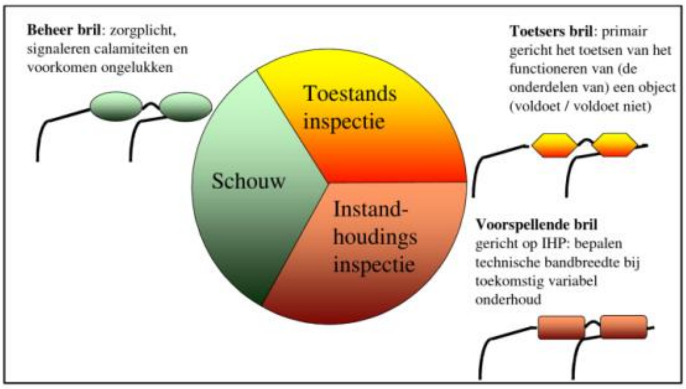



**Figure A3.2 – Inspection categories. [28.]**

Each inspection type has distinct objectives based on object **desired level of functioning** (i.e. based on a desired output). This leads to establish distinct requirements, defined according to the time frame that the inspection is applied. The **content** and **timing** of inspections are defined in line with **risks** identified. The next table identifies the goals defined for each inspection type.

**Table A3.1 – Inspection categories. Goals and results. [28.]**

| Inspection type | Interval *(indicative)* | Goal | Main results |
|---|---|---|---|
| **Regular Inspection** | Daily basis | Detecting emergencies, faults or other weaknesses that are relevant for the context of liability.<br>Take advice to initiate condition inspections. | • Registration of potential liability incidents.<br>• Direct control measures to be taken.<br>• Fixed maintenance.<br>• Condition inspection. |
| **Condition Inspection** | ½ - 2 years | Detecting defects that can affect negatively the object, directly in the short term for its proper and safe operation. | • Capture current state.<br>• Final judgement of parts function, safety and condition (also testing and checking parts of which at normal litigation are not in use).<br>• Propose actions with maintenance. |
| **Maintenance Inspection**[1] | 5 or 6 years | Update/ validate file details of objects or parts of objects. Deliver an opinion and technical preconditions for updating the IHP. | *(see chapter 3)*<br>• Current status data.<br>• Technical bandwidth for future action in the Maintenance Plan (economic optimum and technical extreme moment of intervention).<br>• Advice on adjusting the IHP. |

## 3. Maintenance Inspection. Concepts.

By performing Maintenance Inspections, *Rijkswaterstaat* has **two main goals**. The first goal is to validate "theoretical" risks identified during a *desk-based* assessment. The second is to define mitigation measures to tackle these risks in future maintenance activities, and define the budget needed.

In these inspections, it is defined a **maintenance strategy** ("what"), it is detailed a **maintenance schedule** and its frequency ("when"), and it is analysed the object **condition level** ("how"). The specific requirements to perform a risk inspection vary per object category. Overall, the results of a Maintenance Inspection can be described as *(Table A3.1.)*:

- **Risks** are identified in respect of maintaining the desired quality level, based on:
  - Preliminary studies
  - Found damages and defects
- **Current conditions** determined by the current performance in respect of the desired quality level;
- A scheduling (in time) of **future maintenance** activities necessary to maintain the desired quality level
- A **bandwidth** within which accounted for prioritized and can be clustered with maintenance based on assessment of risks
- Determine **future inspection requirements**.

## 4. Performance criteria.

### 4.1. Context of performance criteria. RAMSSHEEP.

Service Level Agreements (SLA's) are performance criteria established between *Rijkswaterstaat* and the Dutch National Government to the national networks. The translation of Service Level Agreements to object requirements is one of the basic concepts to define an object *Maintenance Plan*. This consists of two aspects. Firstly, the **(functional) requirements** that the object must meet. Secondly, the **functional failure** definition,

[1] *Just the results of* ***Maintenance Inspection*** *are stored in DISK.*

which indicates when an object is no longer acceptable. Therefore, **failure definitions** are based on: *(Figure A3.3)*

1. **Network functions**, which are defined according to object features and component functions;
2. **Network performance**, which is translated into a maintenance concept and generic performance requirements for objects.

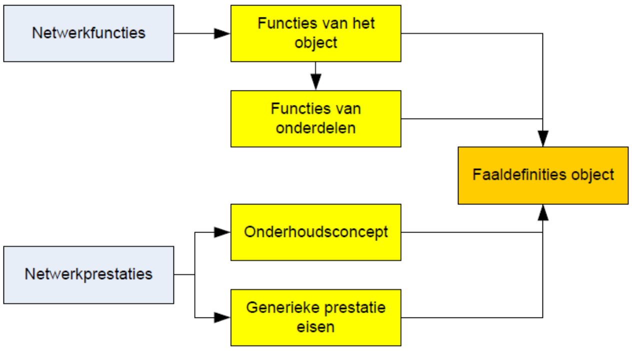



**Figure A3.3 – Translation of SLA's to object requirements. Fundaments. [29.]**

On the basis of a (risk-based) inspection activity, risks are identified for a **desired level of functioning, determined** in the Service Level Agreement (SLA), through the RAMSSHEEP performance criteria *(see section 4.2)*. Although these performance criteria are very generic (in the sense they are applied in a national level), they are particularized to local conditions. This includes aspects, such as economic optimum maintenance, applicable standards and regulations, and conditions arising from an object local usage.

### 4.2. RAMSSHEEP Definition.

Object functions are expressed in terms of RAMSSHEEP aspects *(Table A3.2.)*. The RAMSSHEEP aspects stand for:

- *Reliability*: the probability that the required function carried out under the given conditions for a given time interval.
- *Availability*: the probability that the required function a given arbitrary time can be carried out under the given circumstances. This corresponds to the fraction of the time that the required function can be carried out under given conditions.
- *Maintainability*: the probability that the activities maintenance are possible within the specified time, under circumstances the required function (continue to) run.
- *Safety*: freedom from unacceptable risks in terms of injury to people.
- *Security*: the safety of a system with respect to vandalism and unreasonable human behavior.
- *Health*: being physically, mentally and socially.
- *Environment*: the physical environment.
- *Economics*: the relationship between cost and value.
- *Politics*: political-administrative and social aspects.

**Table A3.2 – RAMSSHEEP Performance Criteria. [28.]**

| Aspect | | RAMS analysis framework |
|---|---|---|
| Reliability | 1.1.R | Satisfy reliability requirements for moving parts and equipment |
| | 1.2.R | Meet structural requirements in relation to damages |
| | 1.3.R | Meet structural requirements in relation to revised standards |
| | 1.4.R | Meet structural requirements in relation to different use |
| | 1.5.R | Meet structural requirements in relation to defects in design, execution or management |
| Availability | 2.1.A | Meet object specific requirements with regard to the fulfilment of the object functions |
| | 2.2.A | Prevention of calamities |
| Maintainability | 3.1.M | Meet requirements relating to the maintainability of components |
| Safety | 4.1.Sa | Meet object specific requirements with regard to the safe performance of the object functions |
| | 4.2.Sa | Prevention of calamities |
| Security | 5.1.Se | Meet the requirements with regard to the prevention of vandalism |
| | 5.2.Se | Meeting the requirements relating to the protection of the object |
| Health | 6.1.H | Meet health and safety decisions |
| Surrounding and environment | 7.1.E | Meet design requirements |
| | 7.2.E | Meet environmental requirements |
| | 7.3.E | Compliance with requirements relating to use/ comfort |
| Economics | 8.1.Ec | Moisture management in order |
| | 8.2.Ec | Preventing widespread or irreparable damage |
| Politic | 9.1.P | Meet requirements for image |

## 5. Risks.

### 5.1. Risk definition.

Risks are potential events characterized by a <u>probability of occurrence</u> and an <u>undesirable result</u> (risk = probability x consequence). During early stages of a management object, and before the object risks are identified, *Rijkswaterstaat* defines the required <u>quality level</u> **(**to that object).

For each object, it is elaborated a concrete risk analysis using the RAMSSHEP performance criteria. A risk controlled inspection requires the inspector to be aware of object requirements to perform its function correctly. This is done before the actual inspection through a *desk-based* assessment.

### 5.2. Risk analysis.

Risks identified in an object may not result of <u>observed damage</u> or <u>object bad state</u>. The state of a component must comply with performance requirements related to the desired level of functioning. As a concept, the description of an action must be functional, and not technical in nature.

The inspector is responsible to determine the level of risk. The probability of occurrence and the consequence determine the severity. The size is expressed in a risk.

In principle, a risk description is not based on a *cause and effect* designation, but in its definition the cause must be clearly defined. Both, primary and secondary *cause and effect* relationships, must be decomposed. The identification of a secondary cause in the analysis may lead to the identification of a risk to any other component. This definition must be always linked to the aspect that risk has more impact (i.e. affecting the desired level of functioning).

### 5.3. Risk level.

Usually, a risk identified can provide information about its extent. *Rijkswaterstaat* determines the principles for interpreting a risk:

(1.) The risk level is determined by the occurrence of the risk and its consequences *(i.e. big chance, low consequence, then risk is low).*

(2.) It is possible that an object has not a requirement for analysis, but nevertheless, a low risk applies.

(3.) The **probability of occurrence** is related to the period of first two years after inspection. This includes the period between the identification of risk and the remedy. A faster response is possible, but this have effect on the availability of land, financial planning and maintenance programs.

(4.) The size of the effect is determined qualitatively in a scale that ranges from 1 (low) to 5 (unacceptable).

The following matrix supports the theoretical risk assessment to the basis of probability and consequence.

**Table A3.3 – Matrix of risk analysis. [29.]**

| | Gevolg | | | |
|---|---|---|---|---|
| **Kans** | **Te overzien** | **Ernstig** | **Zeer ernstig** | **Catastrofaal** |
| Kans van falen is onacceptabel (calamiteit) | 3 - Verhoogd | 4 - Hoog | 5 - Onacceptabel | 5 - Onacceptabel |
| Geaccepteerde faalkans is ver gepasseerd | 3 - Verhoogd | 3 - Verhoogd | 4 - Hoog | 5 - Onacceptabel |
| Geaccepteerde faalkans is gepasseerd | 2 - Beperkt | 3 - Verhoogd | 3 - Verhoogd | 4 - Hoog |
| Hoger dan direct na oplevering, de geaccepteerde faalkans wordt benaderd | 1 - Verwaarloosbaar | 2 - Beperkt | 3 - Verhoogd | 3 - Verhoogd |
| Hoger dan direct na oplevering maar binnen de geaccepteerde faalkans | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar | 2 - Beperkt | 2 - Beperkt |
| Niet hoger dan direct na oplevering | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar | 1 - Verwaarloosbaar |

By considering each performance criteria, *Rijkswaterstaat* defined a guide to support the determination of risks consequences *(Table A3.4)*:

**Table A3.4 – Guidelines to support the analysis of risk consequences. [28.]**

| | | Gevolg | | | |
|---|---|---|---|---|---|
| | **Aspecteis** | **Verwaarloosbaar** | **Klein** | **Groot** | **Ernstig** |
| 1.1-R<br>1.2-R<br>1.3-R<br>1.4-R<br>1.5-R | Voldoen aan betrouwbaarheidseisen voor bewegende delen en installaties<br>Voldoen aan constructieve eisen in relatie tot Schades<br>Voldoen aan constructieve eisen in relatie tot gewijzigde normen<br>Voldoen aan constructieve eisen in relatie tot veranderd gebruik<br>Voldoen aan constructieve eisen in relatie tot fouten in ontwerp, uitvoering of beheer | Invloed op de betrouwbaarheid van het object maar geen invloed op de betrouwbaarheid van de netwerkschakel | Invloed op de betrouwbaarheid van het object maar een beperkte invloed op de betrouwbaarheid van de netwerkschakel | Invloed op de betrouwbaarheid van het object en niet behalen van de vereiste betrouwbaarheid van het netwerk | Invloed op de betrouwbaarheid van het object en grote gevolgen ten aanzien van de vereiste betrouwbaarheid van het netwerk |
| 2.1-A<br>2.2-A | Voldoen aan objectspecifieke eisen met betrekking tot het vervullen van de objectfuncties<br>Calamiteiten voorkomen | Invloed op beschikbaarheid van het object, geen invloed op de beschikbaarheid van het netwerk | Invloed op beschikbaarheid van het object, beperkte invloed op de beschikbaarheid van het netwerk | Invloed op beschikbaarheid van het object waardoor de vereiste beschikbaarheid van het netwerk niet behaald wordt | Invloed op beschikbaarheid van het object en grote gevolgen ten aanzien van de vereiste beschikbaarheid van het netwerk |
| 3.1-M | Voldoen aan eisen met betrekking tot de onderhoudbaarheid van onderdelen | Activiteiten voor beheer, inspectie en onderhoud kunnen in een later stadium moeilijker uitgevoerd worden binnen de randvoorwaarden van gebruik | Activiteiten voor beheer, inspectie en onderhoud kunnen in een later stadium aanzienlijk moeilijker uitgevoerd worden binnen randvoorwaarden van gebruik | Activiteiten voor beheer, inspectie en onderhoud kunnen in een later stadium niet uitgevoerd worden binnen de randvoorwaarden van gebruik en heeft directe invloed op de netwerkprestaties | Activiteiten voor beheer, inspectie en onderhoud kunnen in een later stadium niet uitgevoerd worden binnen de randvoorwaarden van gebruik en heeft grote gevolgen voor de netwerkprestaties |
| 4.1-Sa<br>4.2-Sa | Voldoen aan objectspecifieke eisen met betrekking tot het veilig vervullen van de objectfuncties<br>Calamiteiten voorkomen | Zeer beperkte invloed op gebruikersveiligheid van het object, maar dit blijft binnen geaccepteerde grenzen | Situatie die de geaccepteerde grenzen voor gebruikersveiligheid benaderd | Niet voldoen aan gestelde eisen ten aanzien van gebruikersveiligheid waardoor ongelukken kunnen ontstaan | Reëel gevaar voor gebruikers |
| 5.1-Se<br>5.2-Se | Voldoen aan de eisen met betrekking tot het voorkomen van vandalisme<br>Voldoen aan de eisen met betrekking tot de beveiliging van het object | Bewust ongewenst menselijk handelen, kan leiden tot een ongewenste situatie | - Door ongewenst menselijk handelen, ontstaat een ongewenste situatie; OF<br>- Niet voldoen aan security eisen/richtlijnen zonder dat dit een bedreiging vormt voor veiligheid / functioneren | - Door menselijk handelen, ontstaat een ongewenste situatie; OF<br>- Niet voldoen aan security eisen/richtlijnen; EN<br>- Theoretische bedreiging van veiligheid / functioneren | - Door menselijk handelen, ontstaat een ongewenste situatie; OF<br>- Niet voldoen aan security eisen/richtlijnen; EN<br>- Aantoonbare bedreiging van veiligheid / functioneren |
| 6.1-H | Voldoen aan arbo besluiten | Ontstaan van tijdelijke gezondheidsschade of letsel zonder verzuim | - Niet voldoen aan norm en regelgeving EN/OF<br>- Tijdelijke gezondheidsschade of letsel met medische assistentie/ ziekenhuis opname | - Voldoet niet aan norm en regelgeving EN<br>- Blijvende gezondheidsschade of letsel met blijvende handicap | Blijvende gezondheidsschade bij meerdere personen of letsel met fatale gevolgen |
| 7.1-E | Voldoen aan vormgevingseisen | Beperkte inbreuk op eisen aan vormgeving | Beperkte inbreuk op eisen aan vormgeving | Aan eisen ten aanzien van vormgeving wordt niet voldaan | Aan eisen ten aanzien van vormgeving wordt niet voldaan |
| 7.2-E<br>7.3-E | Voldoen aan eisen ten aan zien van milieuhygiëne<br>Voldoen aan eisen met betrekking tot gebruik/comfort | Geen effect op het functioneren van een ander netwerk maar mogelijk klachten uit de omgeving | - Weinig effect op een ander netwerk; OF<br>- Niet voldoen aan omgevings-randvoorwaarden echter dit heeft geen ernstige gevolgen of aansprakelijkheidsrisico's | - Effect op een ander netwerk; OF<br>- Niet voldoen aan omgevings-randvoorwaarden; EN<br>- Gevolgen voor de omgeving of levert aansprakelijkheidsrisico's | - Aanzienlijke gevolgen voor een ander netwerk; OF<br>- Niet voldoen aan omgevings-randvoorwaarden met ernstige gevolgen voor de omgeving of aansprakelijkheidsrisico's |
| 8.1-Ec<br>8.2-Ec | Vochthuishouding op orde<br>Voorkomen van grootschalige of niet herstelbare Schade | Afwijking van het economisch optimale scenario van < 2,5% | Afwijking van het economisch optimale scenario van < 5% | Afwijking van het economisch optimale scenario van < 20% | Afwijking van het economisch optimale scenario van > 20% |
| 9.1-P | Voldoen aan eisen met betrekking tot imago | Klachten | Imagoverlies lokaal | Imagoverlies regionaal | Imagoverlies landelijk |

## 6. Condition.

### 6.1. Defects (or damage) fundaments.

Defects that are found during an inspection are registered in DISK as a damage. A defect is a deviation relative to a desired state of an Inspection Part (IS Part). This may be technical in nature, such as corroded steel or crumbled concrete, but can cover aspects of performance, such as “*not meeting the environmental standards”*. The severity of damage is expressed as an **injury**.

Severity and extent are combined to create a **normalized condition score**. This score is defined according to NEN 2767. The difference between the condition score and the damage indicator is that the first is a standardized score, and the latter covers both technical and behavioral defects (data failures, maintenance carried out, and the use of the object).

### 6.2. Damage level.

The scope and intensity of the damage is expressed as a damage indicator, in a qualitative scale that ranges from 1 to 6.

1. *No damage*
2. *Limited damage*
3. *Moderate damage*
4. *Much damage*
5. *Advanced damage*
6. *Direct threat to safety or performance*

### 6.3. Condition analysis.

The status of an object indicates whether a Maintenance Part meets the performance requirements defined in the *Reference Documents*. The state of those components is determined on the basis of a desk study**,** and on **damage** identified in the inspection elements (IS Parts).

Standards (both technical and functional) with abstract description are initially assessed through a qualitative interpretation of the situation (i.e. expert judgment). Functional standards are only tested if the required availability is known. For example:

- *Qualitative standard: "the moisture and water should be OK”.*
- *Quantitative standard: "meet structural standards and regulations"*

If this information is not present, the inspector must assess whether the object can meet the standard requirements.
Examples:

- *Technical: the crack formation cannot be greater than a certain value.*
- *Functional: meet the required availability*

### 6.4. Condition level.

The status indicator is an assessment of the technical condition of a Maintenance Part, expressed in a qualitative scale that ranges from **0 (good condition)** to **6 (very poor condition)**, as it is indicated in Table A3.5.

## 7. Quality status.

The object status indicator is the result of a condition assessment of the maintenance component considering the *Reference Documents* (BON/OBR). Failure to meet BON/ OBR does not mean that an unacceptable risk occurs. When concluding an inspection, an overall judgment of an object condition must be determined.

The quality of an element is a combined assessment of **condition** and **risk.** The quality represents the extent to which parts of an object meet standards (condition), and its implications for meeting performance requirements (risks).

The quality status is not determined by inspection agencies. This is determined automatically in DISK, which sets the quality level equal to the lowest damage indicator in the underlying components. This can be manually overridden. For this, the following matrix is used:

**Table A3.5 – RAMS Quality status indicator (condition vs. risk). [29.]**

| | Risk Level of Maintenance Object | | | | |
|---|---|---|---|---|---|
| **Condition Level of Maintenance Object** | **1 Negligible** | **2 Limited** | **3 To oversee** | **4 Serious (high)** | **5 Unacceptable** |
| *0. In good condition* | 0 | 0 | 0 | 0 | 0 |
| *1. In very good condition* | 1 | 1 | 1 | 1 | 1 |
| *2. In good order* | 2 | 2 | 2 | 2 | 2 |
| *3. In fair condition. Risk equipped Attn BON/ RBO.* | 3 | 3 | 3 | 3 | 3 |
| *4. In poor condition. Does not meet the RBO.* | 3 | 3 | 4 | 4 | 4 |
| *5. In poor condition. Does not meet the minimum acceptable level.* | 3 | 3 | 5 | 5 | 5 |
| *6. In very poor condition. Disaster; Direct risk Attn meet the required.* | 3 | 3 | 6 | 6 | 6 |

## 8. Maintenance Plan.

### 8.1. Concepts.

It is of *Rijkswaterstaat's* interest to maintain the performance of *their* networks (in a short and long-term perspective), as agreed in the Service Level Agreement (SLA). To this end, the maintenance strategies are defined in an object **Maintenance Plan.**

A Maintenance Plan, a relevant decomposition of an object, the risks (defined in terms of RAMS aspect requirements), and the expected maintenance activities are recorded for each component. All of these maintenance activities constitute the background to maintain an object (including the financial considerations). In a way, the maintenance requirements provided by this plan translates the needed conditions that makes an object available (in operation).

### 8.2. Maintenance Advice.

The Administrator will periodically prognosis maintenance activities. By being supported by inspection data, the Administrator needs to evaluate the need for adjustment of those planned activities. The goal is to use the level of availability to maintain an object (short and long term perspective), given an available budget. The maintenance strategies used are an important basis for the specific information *(i.e. "what is being viewed", "how often"* and *"what is recorded").* This varies per discipline, and per component type.

On the basis of an actual condition, the Administrator *trades-off* optimized costs, and the risk of an unacceptable situation. To this end, he/she can be supported by principles stated on the *Reference Documents.* The period between the measure advice and the technical measure performance is called the "bandwidth". This input is relevant for the Administrator, in order to distinguish between availability, balancing costs and risk of unacceptable performance of an network (or parts of it).

## 9. Advices.

### 9.1. Risk control.

Risks can be controlled by means of action, which are planned in *Maintenance Plans*. The definition of measures to tackle risks describe the most probable maintenance consequences. Each mitigation measure defined must be coupled to one of the risks. However, the definition of these measures must be approved by each object Administrator, which has the possibility to reduce the risk by connecting it to another measure. Before the risk is coupled, the inspector must determine if the action to which he/she wants to link the risk is indeed, correct. To this end, the inspector has two actions possibilities:

(1) adopt a measure from the default action list, or

(2) define a tailored measure (non-standard).

Risks remain visible if a subsequent inspection activity takes place, and the maintenance action is completed.

Table A3.6 presents a list of possible measure advices. Figure A3.4 presents a model used to support inspectors during the definition of those measures.

**Table A3.6 – Advice strategies. [29.]**

| Advies | Wanneer gebruiken | Opnemen in IHP? |
|---|---|---|
| Geen actie ondernemen | Als een risico is geanalyseerd en niet beheerst hoeft te worden. Benoemen heeft als doel voorkomen dat dit risico bij elke inspectie opnieuw wordt onderzocht | Nee |
| Gerichte Technische Inspectie | Als de ontwikkeling van het risiconiveau zo onzeker is dat deze: • Niet beheerst kan worden in de reguliere cyclus van programmerings- en toestandsinspecties al dan niet gecombineerd met (preventief) onderhoud • En de gevolgen ten aanzien van een van de eisen aanzienlijk kunnen zijn | Ja |
| Meenemen in vast onderhoud | Als risico's met een risiconiveau 3-verhoogd of 4-hoog geconstateerd worden die binnen het vast onderhoud verholpen kunnen worden | Nee |
| Monitoren | Als de ontwikkeling van het risiconiveau bij een geconstateerd risico zo onzeker is dat deze: • Niet beheerst kan worden in de reguliere cyclus van programmerings- en toestandsinspecties al dan niet gecombineerd met (preventief) onderhoud • En de gevolgen ten aanzien van een van de eisen aanzienlijk kunnen zijn • Alleen beheerst kan worden door periodiek gericht een inspectie uit te voeren | Ja |
| Nader onderzoek | Als bij een instandhoudingsinspectie, een risico wordt geconstateerd waarvan het risiconiveau niet bepaald kan worden binnen de scope van de inspectieopdracht, maar mogelijk 3-verhoogd of 4-hoog is | Nee |
| Onderhouden | Als het IH-onderdeel onderhouden moet worden. Vervanging van een of enkele IS-onderdelen of componenten wordt ook beschouwd als onderhoud | Ja |
| Vervangen | Als het gehele IH-onderdeel vervangen moet worden | Ja |

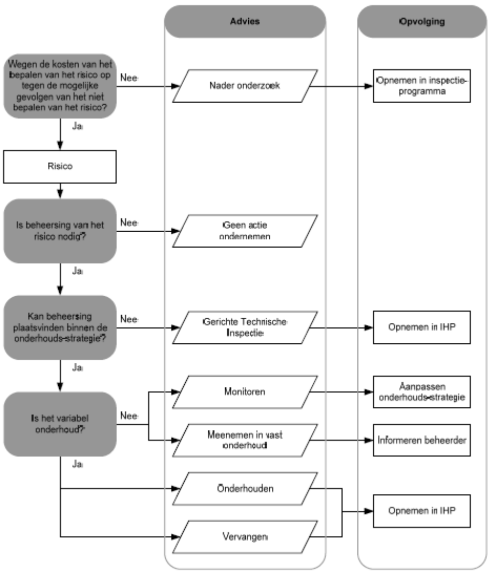



**Figure A3.4 – Process to determine maintenance advice. [29.]**

### 9.2. Advice cost.

The cost field is related to the expected spending on the implementation of maintenance measures. The costs need only to be completed if the *reference* cost, is not valid. This may include standard measures that does not apply, as for example for cost-increasing circumstances that are a result of poor accessibility, or in the case of expensive protective measures.

### 9.3. Advice years and years of extreme risks.

After the determination of a risk level, it is given a prognosis for the risk development within a period of ten years. Inspectors stipulate when the risk is no longer acceptable. The final year is a technical-economic expiry time of intervention defined on the basis of a desired situation. To this end, inspector **does not** take into account economic optimization through clustering, or other organizational environmental conditions. These advices are performed just for object level.

The advice provided also includes the indication of an *optimal time of intervention*. The optimal time of execution reflects the *ideal* time to apply a risk control measure. For each risk an inspector defines a year and a final year. This indication is based on the *Reference Documents* aforementioned.

The inspector needs also to estimate how long the intervention can be postponed. The extreme year is dependent on the risk, and on the expected development in the consulting period. For example, if the status indicator of an IH-part scores 4 (or higher), is the advice years given together with the year of inspection. A state of 3 (or lower) always result in an opinion years for the future. The final year regards the last year of intervention within the bandwidth. This year is determined on the basis of the object desired situation.

An example is presented in [29.]. For part A it is determined state 4, because it does not meet the standard. As a result, the opinion year must be the year of inspection. A risk status with 4 has a short bandwidth. For a component B is determined state 3. It is expected that at the end of 4 years the standards will no longer be met. This year must be the advice year. The risk in the next two years is negligible. The very end year is determined based on estimation. *(Figure A3.5)*

Some risks may hardly change over time.

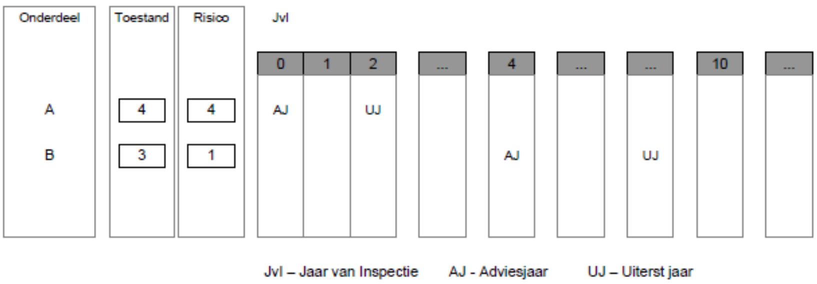



**Figure A3.5 – Example of advice years for inspection and intervention. [29.]**

## 1. Introduction.

In this appendix it is discussed the details of the documents generated during the activities performed during the several processes of the *Life Cycle Maintenance Management* object cycle. These documents are stored in DISK by the respective authors, upon authorization provided by *Rijkswaterstaat*.

Table A4.1 resumes the documents discussed in this Appendix.

**Table A4.1 – Documents store in DISK/ MIOK.**

| Document | | Process which the document belongs | Process step |
|---|---|---|---|
| (1) | Management and Maintenance Design Analysis | Process 1. Decomposition and Maintenance Plan | Step 3. Design Analysis for Management and Maintenance. |
| (2) | Area Data and Decomposition | | Step 4. Definition and Updates of Complementary Areas |
| (3) | Data and Inspection Instructions | | Step 5. Drawing initial Maintenance Plan (IHP) |
| (4) | Draft Maintenance Plan | | |
| (5) | Blank Report | | Step 6. Perform *zero-inspection* |
| (6) | Report *zero-inspection* | | |
| (7) | Report zero-deformation measure | | |
| (8) | Management and Maintenance Plan | | Step 7. Defining Management and Maintenance Plan (B&O Plan) |
| (9) | Inspection Report | Process 2. Inspection and advice<br>Process 3. Update Maintenance Plan | Step 5. Record inspection results |

## 2. Documents generated and stored in DISK/ MIOK.

### (1) Management and Maintenance Design Analysis.

Purpose:

This document aims to **validate the design aspects** relevant for future management and maintenance activities. The object design analysis is performed considering the object function. The purpose of the document is:

- To define a strategy alignment between management and maintenance (for the Administrator use);
- To ensure design verification regarding the fulfilment of management and maintenance requirements, and condition. Internal *Reference Documents* are used to support this analysis;
- To establish interaction between design, and management and maintenance needs through the involvement of designers and maintenance experts;
- To process design changes during the construction phase, or after maintenance or renovations activities. In this case, it must follow an update of the design analysis for management and maintenance (this includes the revision of requirements, conditions or principles for Management and Maintenance activities during the object design and construction).

**Content:**

A design analysis defines requirements, constraints and assumptions concerning the management and maintenance of the object, namely:

- Specific requirements and conditions with regard to management and maintenance;
- Principles for management and maintenance (derived from the functional requirements).

These requirements and conditions (on object and/or component level), also include references to:

- Object lifetime;
- Inspection, maintainability, and/or availability;
- Environmental aspects;
- Safety;
- Constructive and /or traffic engineering requirements regarding allowable of traffic measures;
- Phasing of (certain) maintenance measures;
- Special facilities for maintenance and inspection activities;
- Maximum permissible unavailability due inspection and maintenance.

**Analysis:**

The requirements for maintenance and inspection of object and its parts are determined through a detailed design analysis. Reference Documents can be used for parts that meet the *generic* principles described there (usual requirements, operating conditions and design). For parts without *Reference Documents* available, or that do not meet the generic principles in there, a further analysis must take place. The Administrator, in consultation with the designer and an maintenance and inspection expert, must determine the extent of the analysis needed. This analysis can be supported by available methods or techniques, such as drawing of fault trees, or other models for design optimizations. Possible components of the analysis (object-level / component level) are:

- Maintenance and Inspection requirements (object / component);
- Functional requirements and constraints (use and ambient conditions);
- Risk assessment during usage phase (possible damages, causes and effect of damage, available inspection measures and/ or available maintenance measures);
- Life time analysis;
- Required provisions related to environment and safety;
- Non-availability (object-/parts functions) associated with inspection and maintenance;
- Available *Reference Documents*;
- Conclusions regarding the object and component compliance with management and maintenance requirements, constraints and assumptions.

The extent of this analysis is based on requirements established for the usage phase, and on risks arising from the design with respect to these requirements. Many of the steps are described in functional specifications as detailed in the analysis contracts. System Engineering principles are usually used to support these definitions.

### (2) Area data and decomposition

**Purpose:**

The goal of this document is to **record (or to update) data** regarding:

- **Area** data (*complex* and *management object* characteristics);
- **Decomposition** (definition of maintenance parts (IH) and inspection parts (IS)).

The document works as a basis to perform other activities, namely *zero-inspection*. Due to deviations in the situation encountered, or on the basis of new data that become available, data adjustments might be needed.

**Content:**

- Acreage complex data and control object;
- Decomposition complex and management object;
- Definition of maintenance parts (IH parts);
- Definition of inspection items (IS parts).

### (3) Data and inspection instructions

**Purpose:**

The document aims to capture all the relevant data for future inspections and maintenance activities. This includes design and implementation details, directions and instructions for inspection, maintenance and deformation measures. The document is used as a reference for drafting the initial Maintenance Plan (IHP) and the *Blank Report*.

**Content:**

- Technical requirements and constraints related to inspection and maintenance;
- Data, directions and instructions for inspection and maintenance activities;
- Data and instructions for measuring deformation.

**Issues:**

The document can be updated with new data and instructions regarding the performed maintenance, renovations, or amendments to the developed design.

**Items:**

Instructions for inspections and maintenance data:

- Relevant design data (tolerances, material requirements, product sheets, standards and the like);
- Relevant performance data;
- Other relevant information / details.

The document includes also instructions for different types of maintenance (not exclusively for Maintenance Inspection).

### (4) Draft Maintenance Plan

Purpose:

A Maintenance Plan aims to provide planning information for Administrators. The main purposes of the document is to offer grounds to optimize maintenance activities (including clustering and planning), to understand required budgets, and to plan future maintenance activities.

Content:

A Maintenance Plan includes a prognosis of maintenance measures to be used in future maintenance tasks (defined in a long term perspective), and its relationship with inspection results and schedule information. In addition, the document includes an indication of the (reference) costs for the planned activities and provides a framework for clustering and optimize maintenance activities. A Maintenance Plan includes also a risk management for *management objects*.

Development:

During (or at the end) of a new *management object* execution, a Maintenance Plan is created and record in DISK. The plan definition is supported by standard measures available in the internal *Reference Documents*. These measures are defined on the basis of a *design analysis* (document (1)), and on the basis of *data and instructions* (document (3)).

An initial Maintenance Plan shall also include a global estimation of project costs. During the *zero-inspection* it is examined the extent of those costs based on the possible situations detected. The definition of these risks is relevant for future management and maintenance activities. Thus, this document is expected to be subjected to adaptations and changes during the object life time.

### (5) Blank Report

Purpose:

This report aims at establish final data for the area and management object, and to capture the object's final decomposition (i.e. the definition of maintenance and inspection parts). In addition, the document includes inspection drawings with the indication of inspection parts (defined in a 'checklist' form). Measurement instructions, or measurement protocols to perform those activities (if applicable) are also included in this report.

The document is used as a basic for inspection activities. Nevertheless, if necessary the inspector must adapt this report to the object specifications.

Content:

- Current data area;
- Current decomposition;
- Current overview on the list of inspection drawings with accompanying inspection units;
- Current inspection drawings;
- Current measurement instructions or measurement protocols (if applicable).

### (6) Report zero-inspection

Purpose:

The document captures the baseline for future inspection and maintenance activities regarding the inspection findings performed after the object execution.

Analysis:

Prior to the inspection, the zero-Blanco Report is tested against the 'as-built' condition. In here, it is established the contract for the preparation of the Blank Report (i.e. inspection activities in accordance with the drawings as-built situation), often combined with the command for the execution of this inspection. Observations and measurements (including damages that affect the maintenance schedule) are recorded and photographed (if necessary).

This section also addresses the registration of visible damages accepted from the execution phase. The output values ('0 outcome measurements') are recorded according to the measuring instructions, and according to any measurement protocols defined in the *Blank Report*. This follows the performed *0-inspection* results, as processed in the initial Maintenance Plan.

Content:

- Current Contents;
- Current General view;
- Current Data Area and decomposition;
- Current Inspection Drawings;
- Current Inspection Results;
- Attachments:
  - inspection drawings with marked / indicated damage (where necessary for clarification);
  - damage photos;
  - measurement reports with measurement instructions / protocols (if applicable);

Issues:

- After the definition of inspection drawings, all changes are tested with the program STUFIT2 (Standard Exchange Format for Inspection Drawings). STUFIT defines, among others, layer names, colours, and symbols.
- New drawings must conform to the standard STUFIT2;
- Custom drawings are immutable to the future;
- The drawings must be clearly legible, including indications about the part where the construction is referred to;
- A legend just need to be adjusted as missing or not retrievable:
  - Construction numbers must be in the legend;
  - Drawings are legible.
- It may happen that no inspection drawings are available as an immutable format. This drawings should be produced by inspectors and manufactured in a DWG format.
- All damages inspected must be subscribed in drawings, and inspections activities must be recorded through pictures.

### (7) Report 0-deformation measurement

Purpose:

This document aims to record and to co-ordinates specific (measurement) points of the object (record 0-position). It is used for comparison of subsequent measurements with the 0-position, and to be able to determine any deformations in the future.

Content:

- Identification of the *management object*;
- Location of measuring points (overall drawing microphone positions with additional description);
- Measurement protocols;
- Measurement results.

Issues:

- The measuring points, instructions and protocols are established. Based on this data, it is possible an exact repetition of the measurement.
- The assessment of deformation measurements must take place under technical direction of *Rijkswaterstaat*.

### (8) Management and Maintenance Plan

Purpose:

The purpose of this document is to capture the directions and instructions to maintain a *management object*. The emphasis is given to data provided from the design and realization phase, particularly concerned to inspections and maintenance activities.

The document is used by the Administrator as a reference to determine, or to update specific maintenance measures. It is also a source document to support inspection activities, maintaining relevant data *(for example, deformation measurements),* and to provide maintenance instructions.

Content:

A Maintenance Plan contains all the (basic) information needed to maintain and to manage the object. This information must be in line with:

- Area data and decomposition;
- Relevant design and implementation details, including:
    - Advice and instructions for inspecting and maintaining, and for performing deformation measurements;
    - Initial plans to execute inspection maintenance measures and deformation measurements;
    - Blank report(s), *zero-inspection* report, and the zero-deformation measurement;
    - Transfer data (design data, technical documentation, manuals and warranties).

**Document organization:**

| Chapters | Content |
|---|---|
| 1 | Introduction<br>• Goals<br>• Structure<br>• Management |
| 2 | Identification of Maintenance Object<br>• Data are complex<br>• Data area management object<br>• Outline drawing and photos |
| 3 | Data area and decomposition |
| 4 | Data and Instructions (inspection and maintenance) |
| 5 | Initial Maintenance Plan |
| 6 | Blank report |
| 7 | Report “0-inspection” |
| 8 | Report “0-deformation” |
| 9 | Data transfer |

### (9) Inspection Report

**Purpose:**

The purpose of the inspection is to gain insight into the technical state of an management object. On this basis, the necessary and foreseeable variable maintenance is set. It is also the starting point for the inspection activities where the risks (regarding safety and operation of object parts) are identified.

This document is used to review the implementation of the inspection commissioned, and to determine the substantiation of the manager to bring technical inspection and maintenance advice.

**Document organization:**

| Chapters | Content |
|---|---|
| 1 | Introduction<br>• General<br>• Work description<br>• Inspection purpose<br>• Conditions |
| 2 | Object data<br>• Object description<br>• For study<br>• Situation<br>• Overview (including pictures) |
| 3 | Summary and recommendation<br>• Conclusions regarding the observed state<br>• Status of non-related risks<br>• Overall judgment<br>• Consequences for future management and maintenance<br>• Planning and cost / maintenance plan |
| 4 | Appendices:<br>• Printout of the inspection report (stored in DISK)<br>• Damage photos<br>• Inspection drawings with indication of condition<br>• Measurements (if needed)<br>• New printout of the DISK access<br>• Further research (if needed)<br>• New summary in DISK<br>• Photos of fixed maintenance and related observations and notes. |

## 1. Procedures to register a new *management objects* in DISK.

### a. Registration of a new *management object* in DISK.

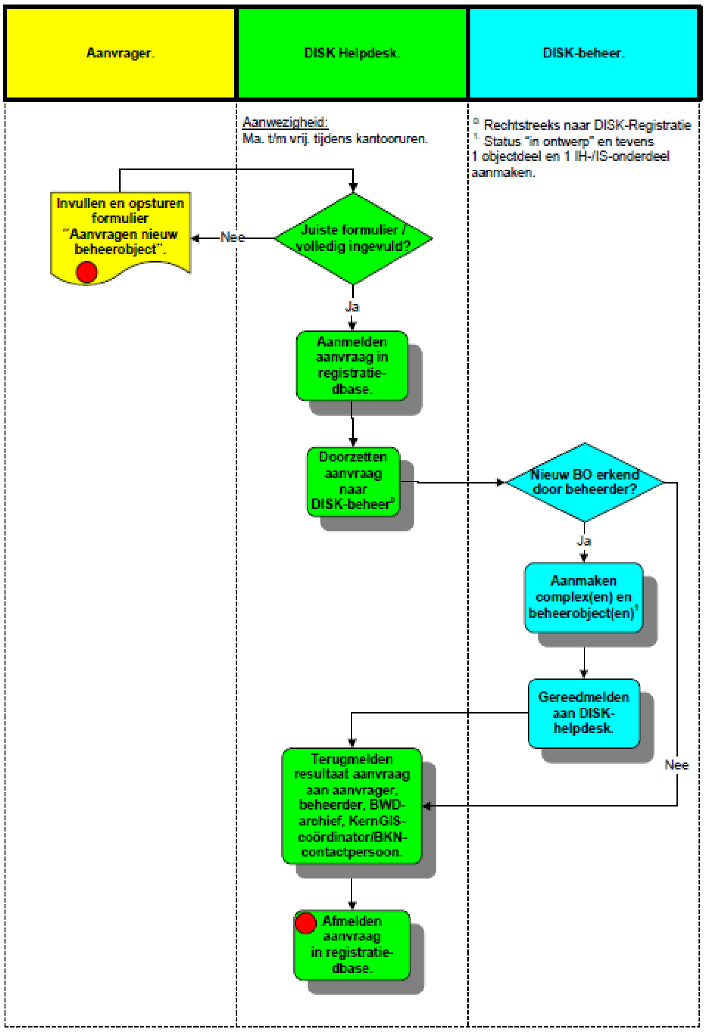



**Figure A5.1 – Procedures to register a new management object in DISK. [45.].**

This procedure starts with an application to DISK helpdesk (*Rijkswaterstaat)* confirming the intention to create a new *management object*.

The application is done through a form that is filled by the applicant, and is sent back via email to the helpdesk. The applicant can be either (1) internal Administrators (RWS), or (2) market parties commissioned to these activities (although with instructions provided by *Rijkswaterstaat*). The helpdesk check the form regarding the data completeness. If the form is not properly completed, it will be returned to the applicant with a request form to fill the missing information.

Upon approval, this data is introduced in DISK by the helpdesk team. The respective content will be checked by the Administrator. If the data is incorrect, it is reported back to the helpdesk via the applicant until the form is corrected. Then, the division into *Complexes* and/or *Management Objects* is defined and created in DISK. The DISK helpdesk registers the request as detailed in the form.

During the registration process it is created at least one *Object Part*, and a correspondent *Maintenance Part* and *Inspection Part*. This is a necessary procedure to prepare the *zero-inspection* activities. The all data *(Complex, Management Object and Object Parts - Maintenance and Inspection Parts)* is updated or adjusted during the inspection processes.

During this process, the helpdesk makes progress reports and send them via e-mail to the applicant, Administrator and *Bouwdienst Archive*. This includes the communication of the *Management Object* codes created in DISK. For *dry Management Objects*, the KernGIS coordinator is informed. For *wet Management Objects*, the *Beheerkaartnat* (BKN) is informed.

The total application takes approximately five working days with maximum of ten days. If the application contains a large number of new *Management Objects* concerned (> 10 units), it should be taken into account a longer lead time.

### b. Classification of a new Management Object in DISK/ MIOK.

For new *Complexes* is a *Complex Code* generated (first free value in the map sheet from 100). Each *Management Object* is addressed to the respective *Complex,* and it is attributed an object sequence number starting at 01.

The combination of a *Complex Code* and an object sequence number for the *Management Object* (Code), are relevant to define the respective *Archive Code* (format: 39H-125-01). If a new object is added to an existing *Complex*, it is only generated an object number. The end result of these procedures is a *Complex Code*, a *Management Object Code*, and also an *Archive Code*.

The existing *Management Objects* follow the same reasoning as for a *Management Object Code*. However, an *Archive Code* differs from the *Object Management Code* in order to maintain the relationship with the existing archive. The *Archive Codes* are also referred to the object parts. The *DISK/ MIOK Archive Code* is used in the communication with the *Bouwdienst Archive*.

An Archive Code must stand under each *Management Object*. Each design specification may have a variation of at least one object part. If the design specifications vary within a *Management Object* (e.g. a movable bridge with one or several ramps), these should be recorded as individual object parts. If this applies to the execution of a *Management Object*, this must be done during the *zero inspection* activities.

In new situations, the object parts are numbered sequentially within the *Complex*. This is a unique number and runs through the last published item part number within the *Complex*. A *Complex* is uniquely identified in DISK/ MIOK through a:

- Topographic map sheet *(example 99H).*
- Serial number (three or four digits generated by DISK/ MIOK) *(example 99H-108)*.

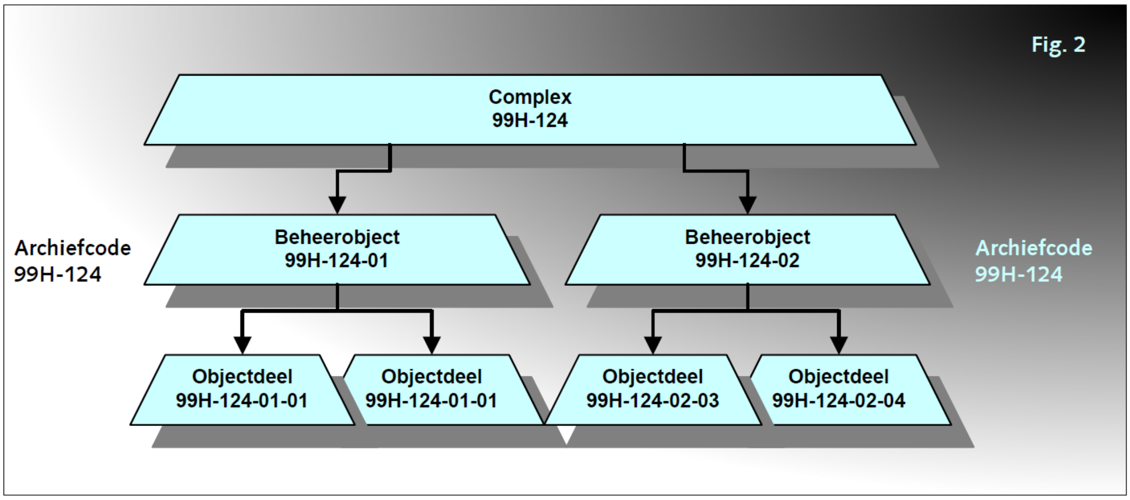



Figure A5.2 – Example of complex and management object codes. [44.].

## 2. Procedures to decompose new Management Objects in DISK/ MIOK.

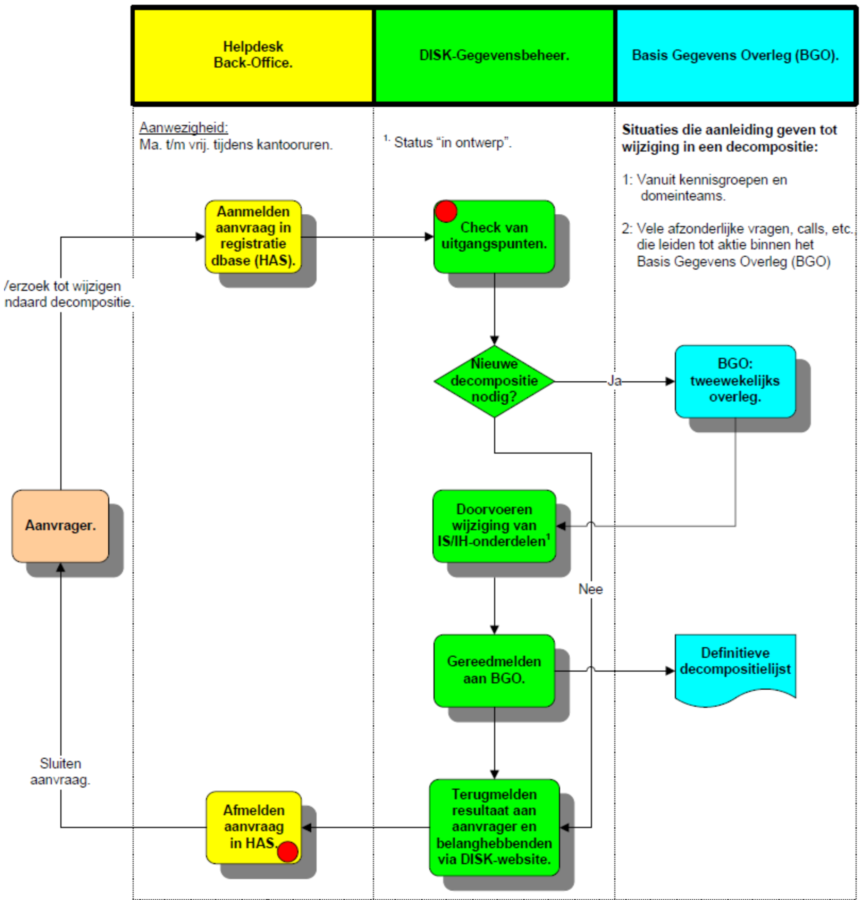



Figure A5.3 – Procedures to decompose a new management object. [46.].

Similarly to the creation of a new *Management Object*, the *procedures* to decompose an object start with the submission of a request to the DISK Helpdesk. The application for a new decomposition can arise from knowledge groups, field teams, or also through a set of questions made via DISK/ MIOK Helpdesk. In this last situation, these questions can be discussed within the Data Base Consultation (BGO).

After submitting a request, the decomposition proposed is analyzed, including the verification of the lexicon and the compatibility with *Reference Documents* available. In case of rejection, the application will not be accepted, and this is reported back through the helpdesk.

Upon approval, the classification of the decomposition is determined, and one or more maintenance and inspection parts are added, changed or deleted in DISK/MIOK. These activities must be developed in accordance with the agreements made by the decomposition team, through the Basic Data Consultation (BGO). This team consists of a number of internal data experts.

When changes are made, the helpdesk reports back (via email) to the applicant, and also to DISK/ MIOK users. If the application contains a large number of changes, the registration process can take up to several weeks.

## 1. Procedures to prepare, perform and register a "zero-inspection" in DISK (after Maintenance Activities)

The figure below presents the procedures for preparation, performing and registering a *zero-inspection* activities.

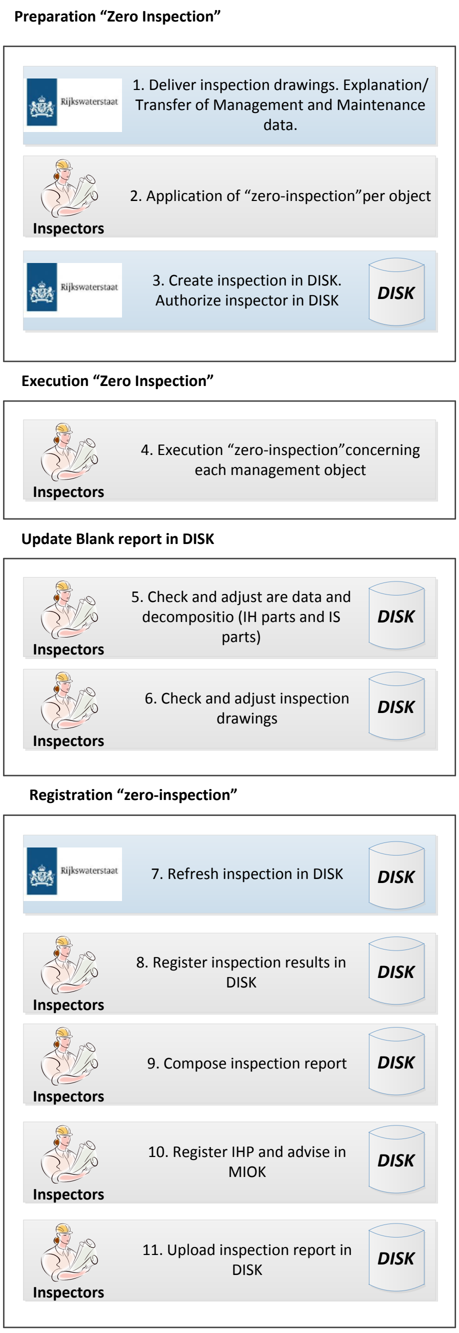



**Figure A6.1 – Procedures to prepare, perform and register a zero-inspection *(based on [27.]).***

### 1.1. Preparation of zero-inspection.

After the conclusion of procurement procedures with a inspection company, *Rijkswaterstaat* prepares a set of *inspection drawings*, developed on the basis of *Reference Documents,* to be stored in DISK.

In order to access these drawings, inspectors need to have permission to access DISK, which is provided by the helpdesk. Thus, two weeks before the implementation of a *zero-inspection*, the inspector must submit a request to assess those drawings. Upon approval, it is required a meeting for each inspector with the (Area) Administrator *(Rijkswaterstaat)*. During this meeting, each inspector receives an information package, with details about the object to inspect.

In the meantime, *Rijkswaterstaat* creates a *zero-inspection* in DISK to, which the inspector is allowed to access. Inspectors can also access to the inspection clusters created in DISK by *Rijkswaterstaat*. This includes access to all objects included in the scope of the contract. During this preparation, the inspector can access the respective *Blank Reports* of the items to be inspected.

### 1.2. Perform a zero-inspection

A *zero-inspection* is a visual inspection performed to the entire *Management Object* (including to the parts to be renovated). Inspection is not needed in all cases, except to the elements that are specified to these activities. This is also valid for mechanical and electrical components. However, the respective Administrator can demand further details, such as a fault data analysis, or a detailed description of functioning problems. In addition, job requirements, regulations, energy performance standards and availability of spare parts can also be required.

Any remaining claims must be manually introduced in the blank inspection drawing. The inspection quality and the zero-remedies need to be tested during the establishment of contract procedures. During the *zero-inspection* implementation, the inspection company must have printouts of the *Blank Report*, the *Maintenance Plan*, and the respective *Inspection Drawings* of the object. These documents are accessed through DISK.

### 1.3. Update Blank Report in DISK/ MIOK

When the *zero-inspection* is concluded, the inspector must refer back to the Blank Report, and if needed, must adapt *area data* and *object decomposition*.

Inspection drawings must be also updated regarding the situation identified. This is particularly relevant for maintenance activities that need to be performed. However, inspection drawings are normally completed after performing a major maintenance.

The Administrator can make changes to the object data without need for adjusting the inspection drawings. Original inspection drawings must be provided to the inspector in a non-editable format. If they are not updated, these drawings need to be adjusted by the inspector.

After posting the necessary adjustments, the inspector receives a complete set of drawings. The old drawings are removed, and the amended and new drawings are uploaded. For this the inspectors have the following rules [27.]:

*"The drawings should be adjusted if the outer situation encountered does not match with those on drawing. While the picture is still true with the outside situation encountered therefore need No inspection drawings to be adjusted. The layout of the drawings and the legend need in that case not have to be adjusted. If the outside does not correspond to the situation encountered drawings, whether or not as a result of maintenance carried out, must be adapted to the drawings. The principle is that the RWS drawings for purpose can handle. In any case, that:*

- *New drawing must meet the internal standards; Custom drawings must in the future be immutable;*
- *The drawing must be clearly legible in any part where the structure is;*
- *A legend just need to be adjusted if parts are missing or not retrievable are on the drawing;*
- *Construction Numbers in the legend do not throbbing to be made;*
- *The drawings must be legible."*

### 1.4. Registration of zero-inspection results

When zero-inspection activities are concluded, their results should by updated data in DISK/ MIOK. If the decomposition is modified, inspection activities must be adjusted in accordance, before any results are recorded. For this process, the inspector might need two working days. After processing all the adjustments, the inspector must inform the object Administrator about the conclusion of the activities.

The next step aims to register the inspection results itself. To this end, the inspector is support by "Data and Inspection Instruction", a document available in DISK. The registration of a *zero-inspection*, regarding the traffic engineering elements, should not be stored in DISK/ MIOK, but must be recorded in a separately VDC module made available to the inspectors. Zero-Inspections of soundproofing structures and culverts (<1.5 m) are also not registered in DISK/ MIOK, but in a separate *.doc* format document.

The end result of an inspection activity is a report containing the *zero-inspection* findings. A report must be composed by a predefined layout (available to inspectors), and should be recorded in DISK/ MIOK in *.pdf* format. The report contains also photographic register of the damages identified during the inspection.

Once the results are reported, the inspectors must update the Management and Maintenance Plan available for the object, and must provide advice in MIOK. In this way, inspection results are automatically linked to the planning. The advice consists in defining measures to tackle risks, (ultimate) implementation date, and respective costs.

Once the inspection is accepted, documents are uploaded in DISK/ MIOK under the specific *Management Object.*

## 1. Procedures to cluster inspections (authorization).

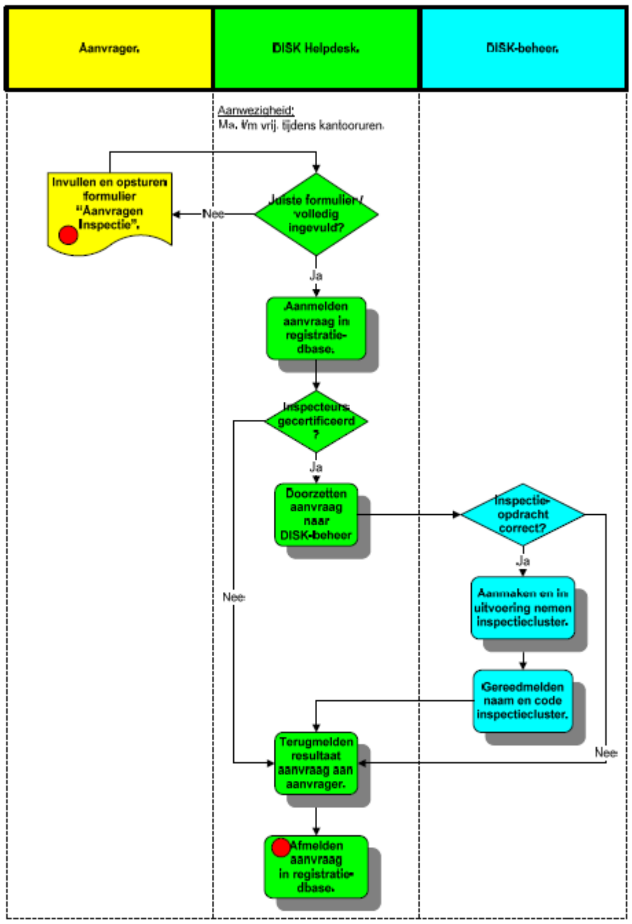



**Figure A7.1 – Procedures to have an inspection cluster created. [47.]**

The activities of clustering inspections start with an application to the DISK helpdesk. The application can be done by (Regional) Administrators, or by the inspection agencies procured for inspecting a group of objects.

The helpdesk team has the responsibility to check the application completeness. If this is not the case, then the application is send back to the applicant in order to proceed with the necessary corrections. Upon approval, the helpdesk records the application and check whether inspectors can access DISK. Inspectors must be certified to access and use DISK, otherwise the cluster is not created. Once these checks are concluded, the helpdesk sends the application form to the (Contract) Administrator. This Administrator has the responsibility to check if the application is in line with the contractual issues.

Upon approval, the DISK Administrator creates the cluster for inspection. In addition, he assigns an inspector to the cluster. The DISK Administrator gives information regarding the cluster names and codes to the helpdesk team. If it appears that there is an incorrect contractual basis for the requested inspection, the application is not accepted, and this is reported back by the DISK helpdesk to the applicant.

Any comments on the process steps are reported back. Finally, the DISK helpdesk registers the application as dismissed. The duration of an application with a completed application may amount to five working days with a maximum of ten days.

## 2. Procedures to cluster inspections (authorization) in DISK/ MIOK.

### a. Procedures to cluster in DISK.

The module *Administration* aims at planning and clustering inspection activities. Clustering in DISK encompasses two activities:

**Step 1. Create an inspection cluster.**

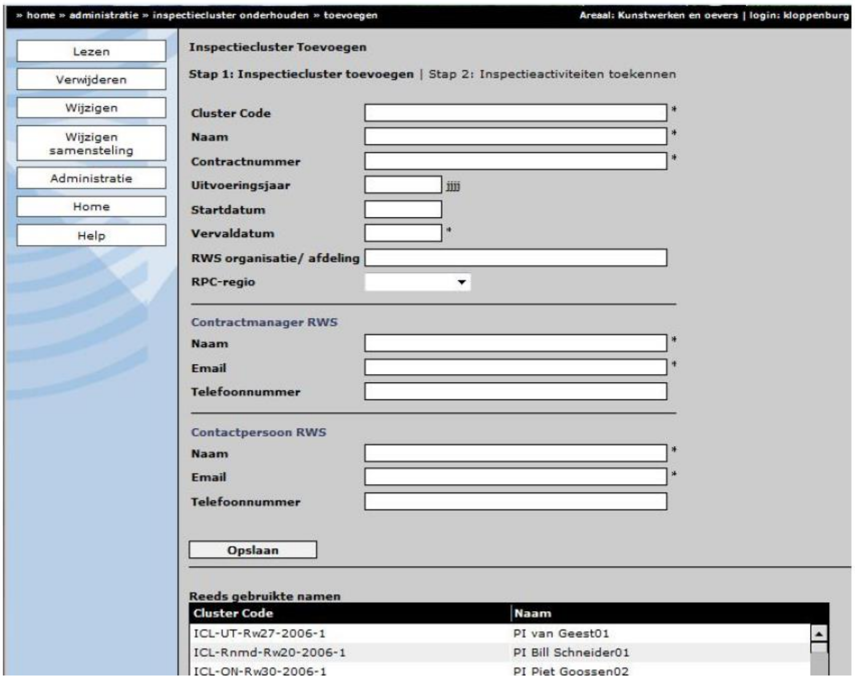



**Figure A7.2 – Create a cluster in DISK [30.]**

**Table A7.1 – Inspection cluster in DISK. Data needed.**

| Nr | Field | Description and definition |
|---|---|---|
| 1 | Cluster code | Product code of the project |
| 2 | Naam | Name of the project |
| 3 | Contractnummer | Code of the project |
| 4 | Uitvoeringsjaar | Implementation year of inspection cluster to be delivered |
| 5 | Startdatum | Expected start date for inspection |
| 6 | Vervaldatum | Expiry date which the cluster must be handled |
| 7 | RWS Org/ Afd. | Organization, Department or District |
| 8 | Contract Man. Naam | Name of contract manager in RWS |
| 9 | Contract Man. Email | Email of contract manager in RWS |
| 10 | Contract Man. Tel. | Telephone of contract manager in RWS |
| 11 | Contact Naam | Name of contact person in RWS |

| Nr | Field | Description and definition |
|---|---|---|
| 12 | Contact Email | Email of contact person in RWS |
| 13 | Contact Tel. | Telephone of contact person in RWS |

## Step 2. Assign inspection activities to the cluster.

This step aims to describe the inspection activities that must be performed.

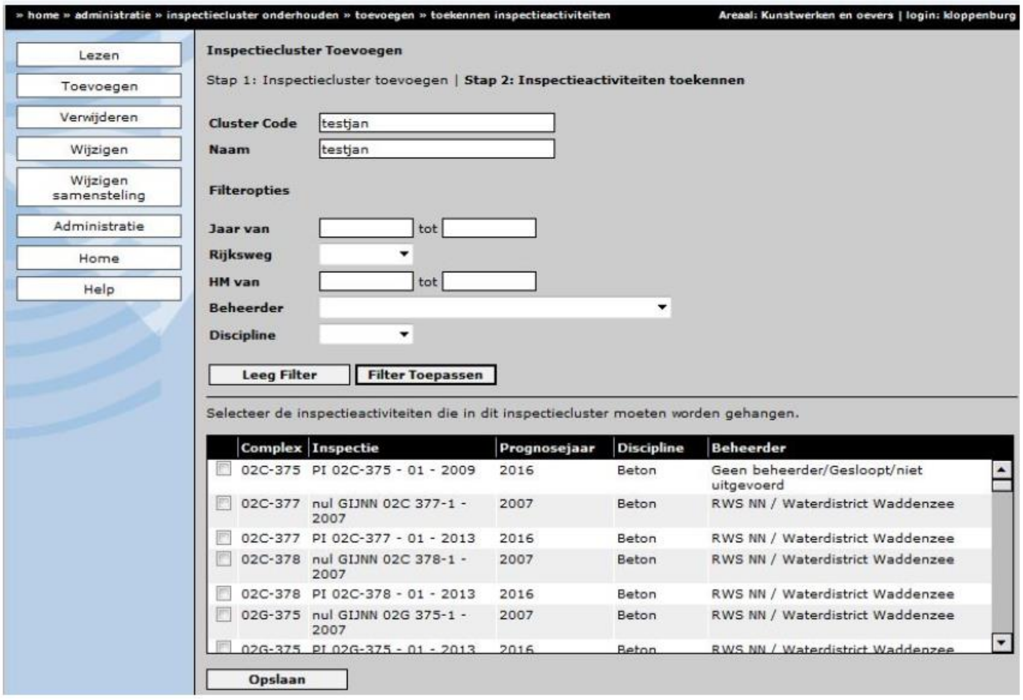



**Figure A7.3 – Assign inspection activities in DISK [30.]**

**Table A7.2 – Assign inspection activities in DISK. Data needed.**

| Nr | Field | Description and definition |
|---|---|---|
| 1 | Cluster code | Indication of the map sheet with serial number of the complex |
| 2 | Inspectie | Inspection description of the appropriate inspection activity |
| 3 | RW | Display of the highway where the complex is located |
| 4 | HM | Indication of the location in hectometres |
| 5 | Prognosejaar | Year in which the inspection is scheduled for the activity |
| 6 | Discipline | Designation of the applicable discipline inspection |
| 7 | Beheerder | Identification of the relevant administrator for the complex |

## b. Planning an inspection cluster


**Figure A7.4 – Planning an inspection cluster in DISK.**

**Table A7.3 – Planning an inspection cluster in DISK. Data needed.**

| Nr | Field | Description and definition |
|---|---|---|
| 1 | Cluster code | Product code of the cluster |
| 2 | Naam | Name of the project |
| 3 | Planjaar | Estimates of the year (YYYY) on which the inspection cluster should be carried out. |
| 4 | Complex code | Indication of the map sheet with serial number of this complex |
| 5 | RW | Display of the highway where the complex is located |
| 6 | HM | Indication of the location in hectometres |
| 7 | Discipline | Designation of the applicable discipline inspection |

## c. Carrying on an inspection cluster

With this screed inspection clusters are under construction. The cluster and all inspection activities given the status "in progress" cannot be changed. After being created inspection clusters are distributed to users with an authorization. To perform this activity, it is needed four steps: (1) step 1. select cluster; (2) step 2. users; (3) step 3. authorization, and (4) step 4. in progress take.

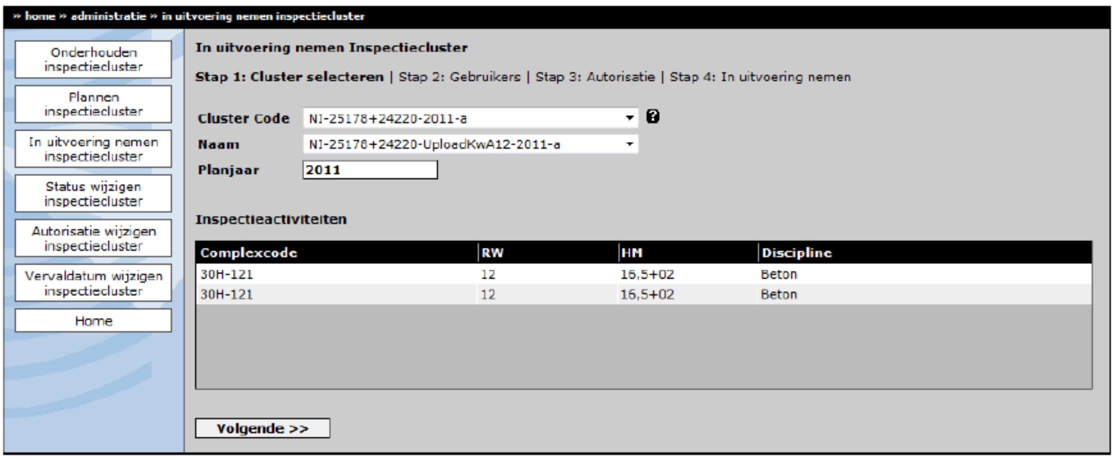



**Figure A7.5 – Carrying on an inspection cluster in DISK [30.]**

**Table A7.4 – Carrying on an inspection cluster in DISK. Data needed.**

| Nr | Field | Description and definition |
|---|---|---|
| 1 | Cluster code | Product code of the cluster |
| 2 | Naam | Name of the project |
| 3 | Planjaar | Estimates of the year (YYYY) on which the inspection cluster should be carried out. |
| 4 | Complex code | Indication of the map sheet with serial number of this complex |
| 5 | RW | Display of the highway where the complex is located |
| 6 | HM | Indication of the location in hectometres |
| 7 | Discipline | Designation of the applicable discipline inspection |

# APPENDIX 2

# INTERVIEW PROTOCOL

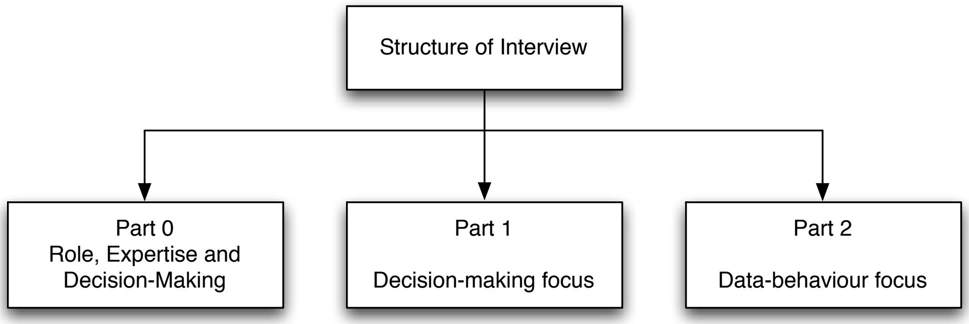
*Number of pages: 4*

## 1. Field study: Maintenance and Inspection decision-making in Rijkswaterstaat.

The purposes of this interview are based in a descriptive and a normative approach. In a **descriptive approach** we aim to characterize the current situation by assessing the perception of decision-makers regarding data characteristics or behaviours, and decision outcomes. Simultaneously, under the context of a **normative approach**, we aim to assess 'ideal' characteristics or behaviours, as perceived by those individuals.

## 2. Structure of Interview.

The interview is organized in three sections, as it follows:



| | | |
|---|---|---|
| RESPONDENT NAME | | |
| ORGANIZATION | | |
| DECISION PROCESS | | |
| DATE | TIME | No. |

## PART 0. PROFESSIONAL ROLE, EXPERTISE AND IDENTIFICATION OF DECISION PROCESS.

Q0. Introduction. Professional role and identification of decision process.

- What are your current position and your level of expertise? What are your responsibilities towards Rijkswaterstaat?
- What is the decision-process you are involved in? Can you briefly describe the decision process?

## PART 1. DECISION-MAKING FOCUS.

### 1.1. CHARACTERISTICS OF DECISION-MAKING.

Q1. Decision objectives.

- How do you perceive the goals of the decision process? In your opinion what are the main decision goals?

Q2. Quality of current decision.

- Focusing on the current decision outcomes, how do you perceive the quality of the decision? How 'good' are the decision outcomes?

Q3. Decision *issues.*

- What are the *issues* affecting the quality of the decision? What is decision *uncertain* about?
  - Why did you come to this perception?
- How often do you deal with these issues during a decision process?
  - Can you describe a situation, or give an example(s)?

Q4. Decision *sources.*

- What are the causes (or sources) of those *issues* (or uncertainties)?
  - Why did you come to this perception?

Q5. Consequences of *issues* and *sources.*

- What are the possible consequences of those *issues* (or uncertainties)?
  - Why did you come to this perception?
  - If applicable, can you describe a situation, or give an example(s)?

### 1.2. MANAGEMENT OF UNCERTAINTIES.

Q6. Strategies used to handle decision-making (behaviour).

- What strategies are already used to manage sources of *issues* (or uncertainties)?

- What criteria is used to the selection of a specific strategy?

### 1.3. Decision-values.

Q7. Characteristics of an efficient decision.

- In an 'ideal' situation, what characteristics (or properties) should those decisions have?
- How should a decision be made? What requisites (criteria, or conditions) should the decision process fulfil to ensure those characteristics?

## Part 2. Data-behaviour focus.

### 2.1. Characteristics of Data Quality.

Q8. Perceived importance of data to the decision process and respective characteristics.

- Which data are considered important to achieve the decision goals?
    - Why did you come to this perception?

Q9. Perceived (existing) characteristics in data.

- How are those characteristics present in data (*format and content*)? How are these characteristics reflected in current *data*?
    - Why did you come to this perception?

Q10. Perceived causes (or influences) on data characteristics.

- What are the causes of problems (or influences) on existing data used?
    - Why did you come to this perception?

Q11. Perceived consequences of existing data characteristics.

- What are possible consequences of existing characteristics of data on the outcomes of the decision?
    - Why did you come to this perception?

### 2.2. Management of data Uncertainties.

Q12. Strategies used to handle data usage (behaviour).

- What strategies are already used to manage sources of issues (or uncertainties)?
- What criteria is used to the selection of a specific strategy?

### 2.3. Decision-values.

Q13. Perceived 'ideal' data and 'ideal' characteristics of data.

- Which other or different data would be needed to achieve the goals of a decision?
    - Why did you come to this perception?
- What characteristics should all data (existing and non-ex) have?
    - Why did you come to this perception?

### 2.3. AREAS OF IMPROVEMENT.

Q14. Identification of possible areas of improvement in the DISK database.

- In your opinion, do you consider any possibility to make greater or better use of the DISK database? Which areas? Can you give examples?

## APPENDIX 3

## REPORT WITH INTERVIEW RESULTS

*Number of pages: 32*

UNIVERSITY OF TWENTE.

Rijkswaterstaat
*Ministerie van Infrastructuur en Milieu*

# OPPORTUNITIES TO SUPPORT ASSET MANAGEMENT DECISION-MAKING PROCESSES THROUGH THE USE OF DISK DATA SYSTEM

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## PERCEPTION ON DECISION-MAKING AND DATA QUALITY:

*Assessment of normative and descriptive perceptions*

**(AMENDMENT)**


**Professional Doctorate Engineering Program**

T.C. Viana da Rocha (University of Twente)

Program Advisors:

Dr.ir. A. Hartmann (University of Twente)

Dr. ir. R. Schoenmakker (Rijkswaterstaat)



Enschede, May 2014

Version 2.0

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- **Appendix 3:** Cause-effect trees with symptoms.

*Background*

Rijkswaterstaat (RWS) is an organization with maintenance responsibilities over three national infrastructure networks: (i) highways, (ii) waterways and (iii) water systems. The civil objects that are included in those networks, such as bridges, tunnels or dams, are regularly submitted to inspection and maintenance activities.

Recently RWS adopted a risk-based inspection approach to support those activities. The approach aims to characterize the risk affecting each object according to the risk framework adopted by RWS. The framework includes a set of qualitative criteria - RAMSSHEEP[1]. This risk categorization acts as an input to define and characterize mitigating maintenance measures, as part of each object's maintenance plan. The risk characterization and the maintenance measures are stored in an internal database: DISK. Both - risks and measures - are used as a basis for the programming of variable maintenance.

However, RWS's practitioners have distinct perceptions about the data that is being collected, stored and used during such processes and about the way data affects decisions. The first perception concerns the characteristics of data used: **data quality**. The second perception regards the way people behave under conditions of uncertainty during a decision process: **behaviour adopted during the use of data in a specific decision-making process**.

The analysis of these perceptions cannot be done separately because their scope overlaps to some extent. For example, the sources of uncertainties in a decision process might be related to the properties of data, might be caused by the manner decision-makers use data or might even result on the way data is interpreted or understood.

*Objective*

This study is part of a PDEng program and aims to understand to which extent those perceptions affect the quality of specific decisions outcomes. To this end, we performed an exploratory field study in the domain of two RWS' decision processes: (i) inspection and maintenance advice and (ii) maintenance programming. Based on this understanding we identified some potential for improvement. This document presents the results of the undertaken data collection.

*Outline of document*

**Chapter 2** presents the data collection methodology and **Chapter 3** provides an overview on the selected decision-making processes. The data collection results are described in **Chapter 4**. A discussion about the potential for improvement – the next phase of this project – is presented in **Chapter 5**. Last, **Chapter 6** lists the bibliographic references used in this study.

[1] RAMSSHEEP: Reliability, Availability, Maintainability, Safety, Security, Health, Environment, Economic and Politics

### 2.1. THEORETICAL BACKGROUND: DESCRIPTIVE, NORMATIVE AND PRESCRIPTIVE APPROACHES

In a rational[2] decision-making process, information plays a crucial role in reducing uncertainty [Citroen, 2011]. Citroen also found that during such process, information is seldom seen as a deterministic factor. As a result, the information properties, such as the quality or the sources, are not yet recognized as vital elements for the decision process.

Another relevant aspect concerns the manner that decision-makers use information. For example, Lee and Dry (2006) mentioned: *"most decisions in the real world must be made under conditions of uncertainty, and so understanding how people reason with incomplete and inaccurate information is a central problem for cognitive psychology"*. Under this context, previous research shows that decision-making processes can be characterized by two approaches:

**(i) Normative approaches:** explores how people **should** make decisions [Marold *et al.*, 2012]. Leo and Dry (2006) named this approach as *substantively rational inference*, as the optimal approach for human decisions under uncertainty.

**(ii) Descriptive approaches:** analyses and describes different **heuristics and biases** in a decision-making process under uncertainty [Marold *et al.*, 2012]. Leo and Dry (2006) named this approach as *procedurally rational inference* (providing accounts of heuristic process that make fast and accurate decisions based on uncertain information). By discussing the nature of rationality, Smithon (2008) explained the concepts of heuristics and biases through the use of irrationality. Smithon defended that mental shortcuts to reasoning (heuristics) used by people cause them to fall prey to irrational tendencies (biases). Thus, heuristics and biases tend to justify that an individual preferences change all time and are affected by different factors in relation to the context and situation of decision-making.

As decision-makers systematically violate normative principles, **prescriptive interventions** are sometimes implemented to support them to get closer to a normative ideal [Marold *et al.,* 2012: Lipshitz & Cohen, 2005].

### 2.2. METHODOLOGY USED

A data collection methodology was defined by making use of the concepts described in Section 2.1: normative, descriptive and prescriptive. Figure 1 shows the data collection methodology adopted for data collection and analysis.

[2] Citroen (2011) defended that organizational decision-making processes tend to be based on a *rational* approach: process in which decision is supported by the analysis of circumstances, alternatives and consequences of decision-making. In a rational approach, information *"is used as a basis for the judgement on the implications of feasible alternatives for the decision to be made in such a rational process"*.

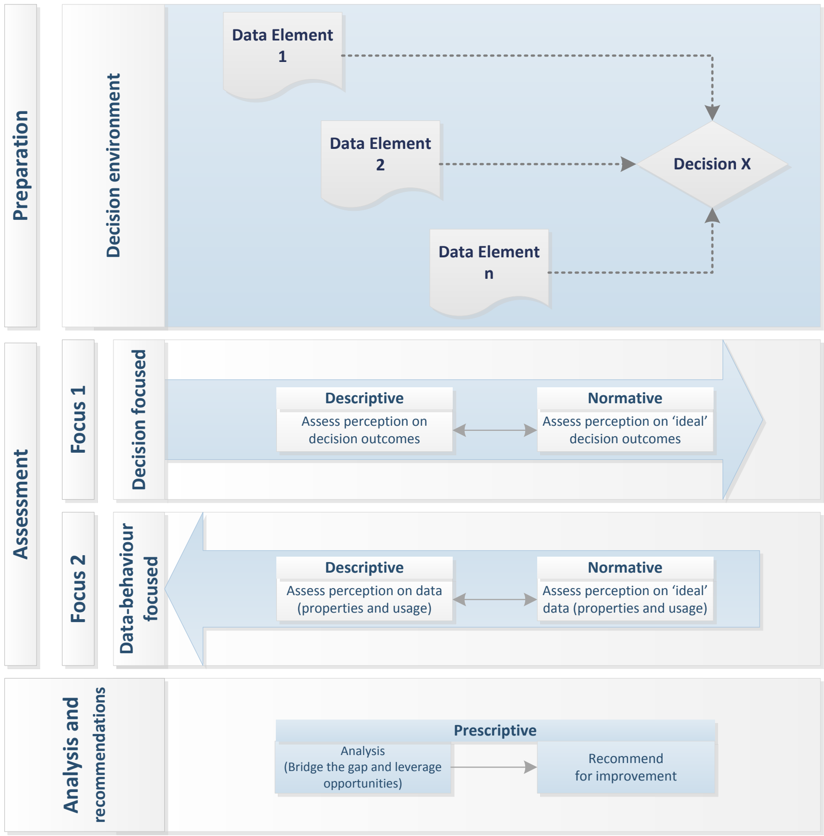


**Figure 1 – Data collection methodology.**

➢ **Preparation phase**

During the *preparation phase* we characterized the decision environment. Our goal was to select and characterize two decision processes that make use of DISK data. To each process, it was given a particular emphasis to the identification of decision objectives, to the process structure and to the participants involved.

➢ **Assessment phase**

During the *assessment phase* we focused in two areas simultaneously:

***Focus 1. Decision-process (and its outcomes)***

We aimed to understand how is the decision currently perceived by decision-makers [descriptive] and how do these decision-makers perceive an *ideal* decision process [normative].

***Focus 2. Data used, its quality and the way it is used (behaviour)***

We focused on the data used in the decision processes, both in terms of quality criteria (affecting data content and data format) and in terms of data usage (behaviour). In the context of a specific decision process [descriptive], we aimed to understand *which* data is being used and *how* it is being used.

Similarly to the previous phase, this phase also aimed to assess the perceived *ideal*, both in terms of data quality and in terms of data usage [normative].

- **Analysis and recommendations phase**

  The last phase of the methodology aimed to:

  (i) to bridge the gap between the perceptions assessed by *trading-off* both perceptions: descriptive and normative; and

  (ii) to identify opportunities or potential for improvement.

### 2.3. Structure of interview

The data collection process was based on a set of semi-structured interviews. The add-value of a semi-structured interview is the allowance of new ideas to be brought during the interview. However, the main structure of the interview was in line with the data collection methodology (Section 2.2). To provide guidance to the interviewer, it was prepared a protocol with a group of questions and sub-questions. The interview protocol is presented in Appendix 1.

### 2.4. Subjects

Between 06.12.2013 and 06.03.2014, we performed 14 interviews, involving a total of 18 respondents. Each respondent has functions in one of the decision processes selected (Section 3.1): inspection and maintenance advice process or maintenance programming process. Table 1 characterizes the respondents involved in the interviews. Further details about the respondents can be found in Appendix 2.

**Table 1 – Characterization of respondents.**

| Decision processes | Organizations | Functions | Nr. Interviews | Nr. Participants |
|---|---|---|---|---|
| Inspection and maintenance advice | Private engineering firms | Engineers/ Consultants | 3 | 5 |
| Maintenance programming | RWS Regional | Maintenance programmers/ Asset Managers | 7 | 9 |
| Inspection and maintenance advice<br>Maintenance programming | RWS Central | Inspection coordinators<br>Programming coordinators | 3<br>1 | 3<br>1 |

### 2.5. Method of data analysis

The interviews were recorded and analysed in a chronological order. The perceptions provided by the respondents were categorized in underlying themes. An overall portrait of the results was constructed, as it is presented in Chapter 3.

### 3.1. PROCESSES THAT MAKE USE OF DATA IN DISK

DISK is a custom-based database developed and implemented by RWS. It stores data related to inspection and (variable) maintenance of all the civil objects managed by RWS. The data stored in DISK is frequently used to support various decision-making processes within RWS. Among them, we identified and selected two processes that are vital to the effectiveness of the maintenance management program of civil objects: (i) inspection and maintenance advice process and (ii) maintenance programming process. Each process is described in the following sections. Figure 2 allocates the participants to the respective decision process.

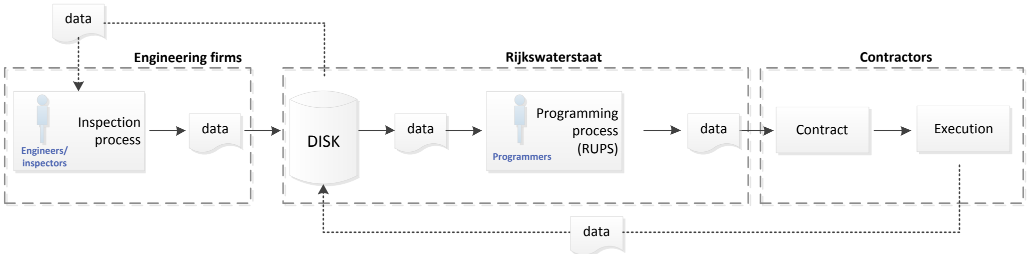


**Figure 2 – Simplified process scheme addressing the respondents to the respective process.**

### 3.2. INSPECTION AND MAINTENANCE ADVICE PROCESS

Each civil object must be submitted to operational services, as inspection and maintenance activities. These activities are part of a maintenance management programme cycle (Figure 3). The cycle is composed by a set of processes that must frequently occur during an object lifetime: (1) decomposition and maintenance plan, (2) inspections and maintenance advice, (3) adjustment of (object) maintenance plans, (4) clustering and optimization, (5) maintenance execution and (6) end of service life.

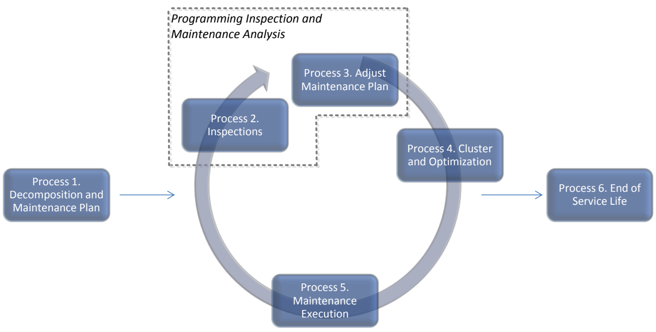


**Figure 3 – Cyclic process maintenance management for civil objects.**

It is a political choice of RWS to outsource inspections and maintenance activities to private market parties. Thus, private engineering firms are procured to perform inspections and advice mitigation maintenance measures (Processes 2 and 3, Figure 2). When combined, the processes include the following steps: (i) information transfer, (ii) initial property risk analysis, (iii) inspection, (iv) maintenance advice and (v) reporting. During the steps (ii) and (iii) engineers perform risk-based assessment decisions and during the step (iv) all the maintenance measures are defined by adjusting each object's maintenance plan. Thus, data stored in DISK is vital to support the decisions underlying these steps (Figure 4).

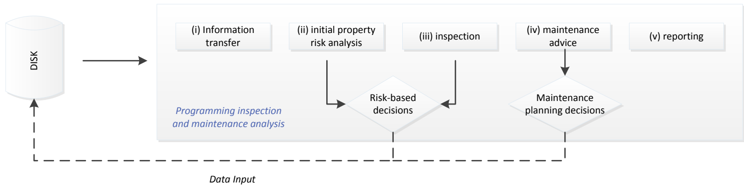


**Figure 4 – Scheme of inspection and maintenance advice processes.**

### 3.3. Network maintenance programming

RWS is divided in several regional departments, such as: South Netherlands, Eastern Netherlands, Northern Netherlands, North Holland, South Holland, Zeeland, North Sea and Central Netherlands. The regional departments are responsible for the maintenance of the infrastructure networks located under their geographic jurisdiction.

To this end, programmers combine all the object's needs, such as pavements, civil works or surrounding interventions into yearly maintenance programs. To support those activities, programmers use a planning tool: Rijkswaterstaat Uniform Planning System (RUPS).

However, the programming process is affected by two main conditions: (i) the budget available to the region and (ii) the network performance levels defined in agreement with the National Government. The goal is to match the maintenance needs with the budget available and to transform those needs into implementation projects. Figure 5 shows the organization of RUPS according to the governance level: central and regional.

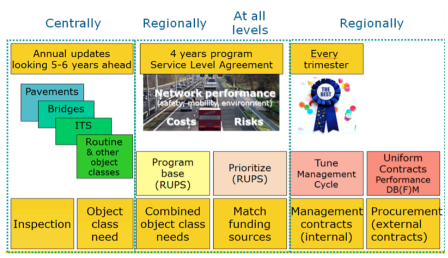


**Figure 5 – Maintenance management programs [adapted from Paffen *et al.*, 2011].**

On a regular basis DISK and other data sources send data to RUPS. This data is related to the current object condition level, risks and maintenance measures with costs and advised period for implementation. Figure 6 shows the main phases of a maintenance programming process.

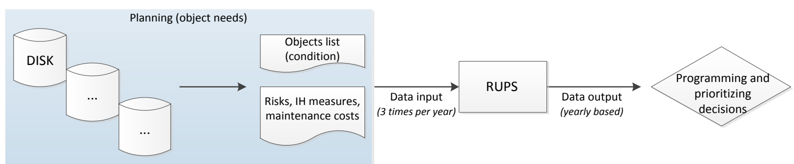


**Figure 6 – Scheme of network maintenance programming.**

Respondents were asked about their perceptions on limits and barriers of both (i) the decision outcomes and (ii) the quality and usage of DISK data. The comments highlighted several challenges, which were organized in five major groups, as explained in the following sections.

## 4.1. LIMITED USEFULNESS OF THE DATA MANAGEMENT SYSTEM TO SUPPORT THE INSPECTION PROCESS

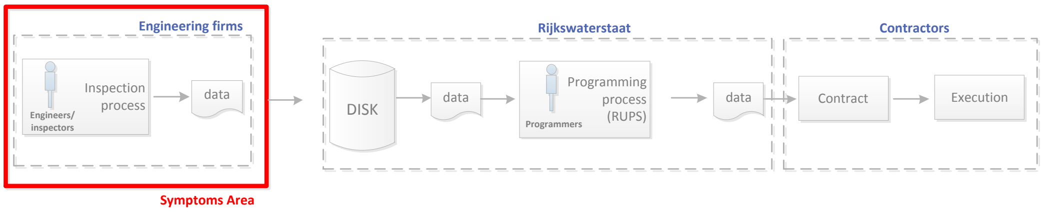


**Figure 7 – Limited usefulness of the data management system to support the inspection process: symptoms area in the maintenance management program.**

### SYMPTOMS

Data collected during the inspection process is used not just for current decisions but is also the basis for future inspection processes. Thus, the quality of this data is vital to the effectiveness of the inspection processes – and ultimately, to make cost-effective decisions. However, engineers expressed their concern about the quality of data being currently produced and delivered through the inspection process. The sources of these perceptions are described as it follows:

*i. Lack of mechanisms available to support risk assessment*

The lack of mechanisms available to support the inspection process is perceived as an existing gap in the current data management system. This is particularly relevant during the phases where risk must be assessed, because the risk framework consists of qualitative criteria: the RAMSSHEEP (Figure 8). For example, during an object analysis an engineer can perceive a risk level 2, while another can address a scale of 3. The lack of supporting mechanisms to the assessment of risk seems to give engineers freedom to adopt their own assessment methodologies. By adopting their own reasoning procedures to derive to a risk value, engineers might arrive to different perceptions of the risk involved. Thus, such flexibility is perceived as a source of ambiguity and subjectivity, with impact on the quality of the data produced.

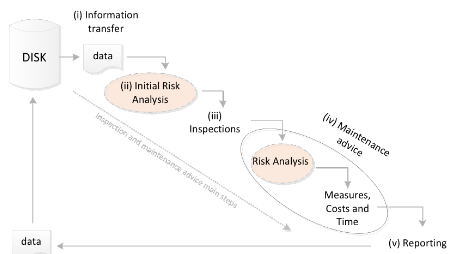


**Figure 8 – Impact of the lack of supporting mechanisms in the inspection process steps.**

*ii. Reasoning of previous inspection data not available*

Engineers pointed that the results of previous inspections are seen as a set of risk values and advised maintenance measures. Those results do not seem to reflect the reasoning that previous firms used. Thus, engineers claim that instead of focusing on the reasoning of the most recent inspection results, they frequently need to re-check old historical inspection data. Such process is perceived as time consuming and inefficient.

*iii. Problems with data acquisition: Inaccurate or inexistent assessment of data needed*

Data stored in RWS is delivered to the engineering firms at the beginning of the inspection process. However, engineers have the perception that vital data is sometimes inexistent or difficult to find because it is fragmented within the organization. As a result, engineers claim that they need to perform additional data requests to RWS in order to have access to complementary data. These additional procedures are perceived as barriers to the timely acquisition of data and to the efficiency of the inspection process. The classical example given by respondents is the missing of technical data related to old objects. Also data from maintenance activities – known as 'as-built' data - is rarely found in DISK.

Figure 9 shows the cause-effect tree of these perceptions. The tree can be also found in Appendix 3.

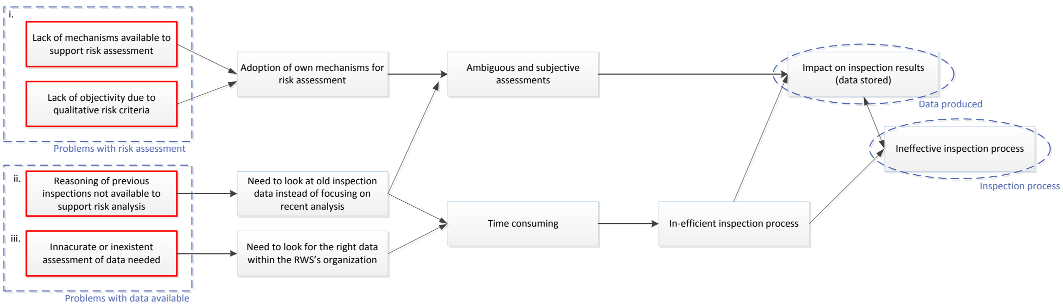


**Figure 9 – Cause-effect tree: limited usefulness of the data management system to support the inspection process.**

#### RECOMMENDED ACTIONS PERCEIVED BY PRACTICIONERS

Engineers claimed that if the perceived difficulties were addressed to some possible interventions, the effectiveness of the inspection process would improve. Thus, they suggested some interventions.

- *Introduce decision-support tools to the inspection process*

To minimize or overcome the impact of the symptoms, engineers emphasized the need to improve the DISK contribution. They defended the introduction of decision-support tools to guide the inspection process and to support the inspector towards the reduction of uncertainties inherent to risk assessment.

- *Introduce information management systems*

*Where is the data that we need? What is the availability status of such data?* These are examples of questions that respondents would like to have answered. They suggested the introduction of an information management system that provides support to data identification, location and availability. They defended that such tool would contribute to improve the efficiency of the inspection process.

- *Make ideal data available*

Engineers consider that data is a key enabler for good decision-making. Therefore, they defend that *ideal* data should be available. When questioned about the ideal data for the decision-making processes, they identified four main data groups perceived as needed: (i) object description data: descriptive and technical data, including object description and physical and functional breakdown structure, (ii) previous inspection data: risk results, maintenance measures, costs and implementation schedules, (iii) data about the implemented maintenance activities: "as-built data" and (iv) data from condition-based inspections.

- *Improve the assessment of data needed*

Having data on time is perceived as vital to the efficiency of the inspection process. Thus, engineers defended the introduction of data assessment procedures before the inspection process takes place. According to them, a timely data delivery increases the support of the inspection process – and ultimately, intensifies the possibility to make more accurate decisions.

### 4.2. LIMITED USEFULNESS OF THE DATA MANAGEMENT SYSTEM TO SUPPORT THE PROGRAMING PROCESS

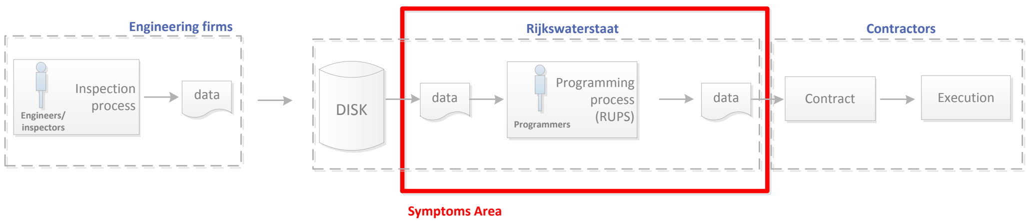


**Figure 10 – Limited usefulness of the data management system to support the programming process: symptoms area in the maintenance management program.**

#### SYMPTOMS

Programmers expressed their concern about the outcomes of the programming process. According to these practitioners, these results have impact on the way that risk is tackled, which can compromise the effectiveness of the programming process. The sources of these perceptions are described as it follows:

*i. Difficulties to understand inspection data*

Programmers claim to have difficulties to understand the reasoning behind data provided by DISK. Also the lack of decision-support mechanisms to the programming process is perceived as an existing gap in the current data management system. Such lack leads programmers to make use of a great deal of assumptions and to incorporate subjective judgments during the programming process.

For example, programmers claimed that they lack understanding about risk results, both in terms of risk magnitude and in terms of risk criteria. Also the organization of the object seems to be unclear. For example, they struggle to understand if a risk level 3 in a joint is more relevant than a risk level 4 in a beam. Another example regards the economic assumptions assigned to the advised maintenance measures. Programmers claim that these measures focus on a single maintenance strategy instead of being supported by a comparative analysis that justifies the choice. In addition, the maintenance costs defined through inspections are just relative to the measure implementation (i.e. near costs) and do not include any lifecycle consideration. Programmers also claim to lack data about the impact of those measures, regarding the costs of the traffic due to the performance of maintenance activities. Also data from DISK does not make any reference to the relationship between the maintenance measures defined and the impact on the performance indicators (PIN-SLA).

*ii. Difficulties to rely on inspection data*

Regional departments highlighted several problems concerning the quality of inspection data. They consider that the flexibility given to the engineering firms, the subjective nature of the inspection and the experience of those professionals might affect the quality of the inspection results. In addition, regional departments tend to believe that engineering firms lack knowledge on the local risks affecting an object. As a result, inspection data is not always perceived as reliable, leading programmers to introduce changes on the data results. This perception can also give room to subjective assumptions according to criteria adopted by each regional department (or programmer).

Figure 11 shows the cause-effect tree of these perceptions. The tree can be also found in Appendix 3.

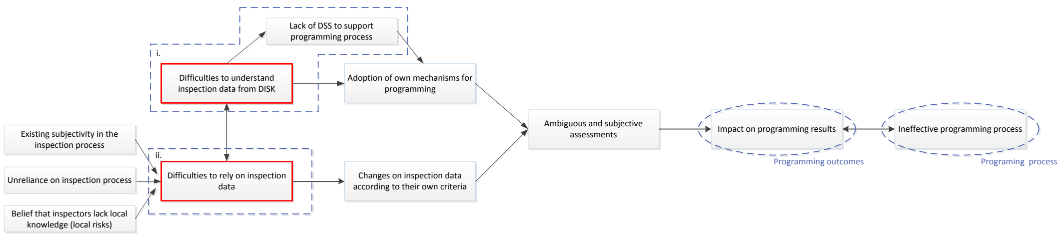


**Figure 11 – Cause-effect tree: limited usefulness of the data management system to support the programming process.**

### RECOMMENDED ACTIONS AS PERCEIVED BY PRACTICIONERS

Programmers claimed that if the perceived difficulties were addressed to possible interventions, the effectiveness of the programming process would improve. Thus, they suggested some interventions.

- *Introduce decision-support tools to the programming process*

Programmers have the perception that risks need to be better understood. To this end, they supported the introduction of decision-support tools to improve the risk understanding during the programming process. In addition, they also recommended the introduction of a risk characterization for each object type in order to better understand the risk involved in a network level.

- *Introduce information management systems*

Similarly to engineers, also programmers suggested the introduction of an information management system to support data identification, location and availability. They defended that such tool would provide support to the programming process because it would give programmers more grounds to know more about data availability. In addition, such tool would contribute to improve the communication between regional departments, specially facing similar management issues.

- *Make ideal data available*

Regarding the ideal data to make decisions, programmers added a few more items to the list provided by engineers. To these practitioners the ideal data is assembled in six groups: (i) the inspection results from the inspection process, (ii) the object risk analysis based on failure analysis tools (eg. FMECA or ETA), (iii) the current object performance level based on the component status and current and expected degradation models, (iv) object performance level based on the current SLA (impact of the maintenance measure on the PINs), (v) importance of the object in the network and (vi) plans for the future, particularly affecting the expected object end of life.

### 4.3. Problems with communication between maintenance management processes

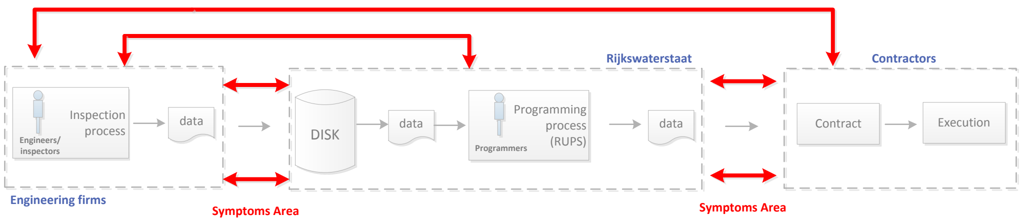


**Figure 12 – Problems with communication between maintenance management processes: symptoms area in the maintenance management program.**

#### Symptoms

Regional managers and programmers presented concerns on the manner that specific processes are interacting with each other. Such symptoms raise doubts on the quality of data generated in each decision process – and ultimately on the effectiveness of the decision process itself. Several aspects contribute to these perceptions, as it follows:

*i. Non-optimal communication between processes from the maintenance management programming*

Regional practitioners consider that changes, adjustments or assumptions implemented during the different processes have impact on the decisions-making processes (Figure 13). To this end, updated data in vital to the effectiveness of decisions.

However, the processes that interact with DISK data just have a 'one-way' communication, which means that data is not up-dated when changes occur. Such lack of monitoring can lead to substantial differences between measures planned and measures implemented at the end of the maintenance management program.

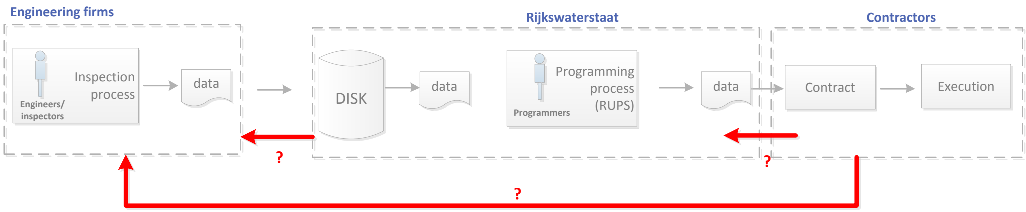


**Figure 13 – Perceived problems with communication between processes.**

The classical example concerns the programming process, where maintenance measures are usually changed or adapted. Such behaviour is based on assumptions adopted on a regional - or even on a personal - level and the reasoning supporting such choices is not registered or communicated to DISK. Similarly, the measures sent to the market (i.e. to be executed) are not known to DISK, which raises concerns that the market might adopt different measures than those planned during the inspection process. Such behaviour might seriously affect the risk involved in an object, both in terms of criteria and in terms of magnitude. Another example concerns the lack of input from contractors to the DISK system ("as-built" data). At the source of these claims are (i) the behaviour of contractor based on damage (i.e. lack of risk knowledge), (ii) contract limitations to address a risk-based performance and (iii) limitation in the communication between RWS and the contractors.

*ii. Lack of proactive communication between processes*

Practitioners also perceive that the processes from the maintenance management program lack proactive communication. Those processes are perceived as long and rigid, in the sense that they do not overlap with other processes. However, a proactive behaviour is seen as vital for critical situations. For example when an object in facing high risks and needs an urgent intervention, engineers claim to not have grounds to raise awareness both on programmers (on the need to address urgent mitigation measures) and on contract managers (on the need to speed-up the maintenance execution contract to the market).

Figure 14 shows the cause-effect tree of these perceptions. The tree can be also found in Appendix 3.

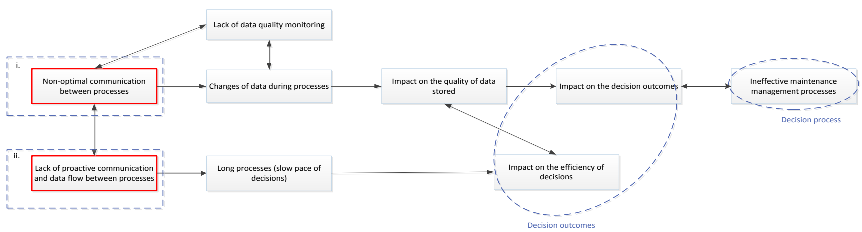


**Figure 14 – Cause-effect tree: problems with communication between maintenance management processes.**

### Recommended actions as perceived by practicioners

Practitioners claimed that if the perceived difficulties were addressed to possible interventions, the effectiveness of the maintenance process would improve. Thus, they suggested some interventions.

- *Promote better interaction between processes*

RWS has the ambition to move towards a performance-based maintenance program, where variable maintenance will be adjusted according to the results from condition inspections. Such future practice will bring substantial changes to the existing procedures. Thus, practitioners defend a better process communication between maintenance processes - from inspection to execution.

In technical terms this could be achieved by guaranteeing the monitoring of data and decision-making during the maintenance processes. One suggestion is to close the maintenance cycle by introducing contractual mechanisms that leads contractors to easily up-date data in DISK with the measures implemented and the *new* risk level.

Another suggestion includes the interaction between parties. Exchange knowledge between parties is perceived as vital to the practitioners: (i) from regional department to inspection team to explain the context where the objects are located and (ii) from inspection team to regional department to explain inspection results. Practitioners believe that such procedures would promote the production of better data and overall, it would facilitate the decision-making processes.

## 4.4. Problems with implementation of the inspection framework

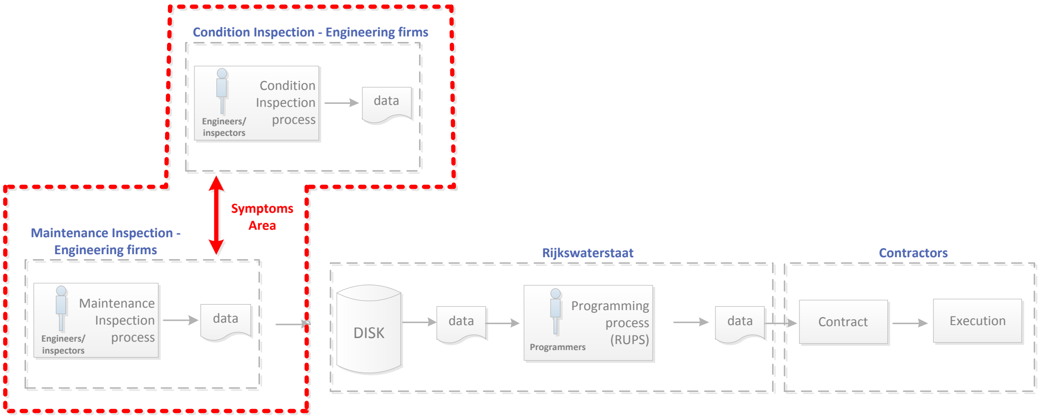


**Figure 15 – Problems with communication between inspection frameworks*:* symptoms area in the maintenance management program.**

### Symptoms

Three inspection types compose the inspection framework adopted by RWS: routine, condition and maintenance. The goal of the framework is that each inspection type acts complementary to each other by having different purposes, timeframes, databases and being independently procured to the market. Despite recognizing the importance of data from *condition inspection*, practitioners involved in *maintenance inspections* consider these inspections weakly integrated. As a result, the outcomes of a *maintenance inspection* are perceived as inefficient. This perception is sourced in a number of aspects.

*i. Incomplete implementation of inspection framework*

There is a perception that the inspection framework is not completely implemented, which gives practitioners the felling that inspection goals are not aligned. Some practitioners claimed that this is due to the bad implementation of a performance-based maintenance approach, which is the result of a wrong interpretation of performance-based contracts.

*ii. Condition-inspection data lacks quality properties*

Both inspection types have distinct focus. While the maintenance inspection is based on risks, the condition inspection is focused on condition. Consequently, both types are using different standards: RAMSHEEP and NEN2676, for risk and condition, respectively. Thus, they claim that the data collected and stored during condition-inspection lacks vital properties to support a risk-based inspection: data lacks a clear relationship between condition level and risk level. Furthermore, data produced in both inspections lacks controlling mechanisms. The quality of data stored in RWS has limitations.

*iii. Lack of knowledge of condition-inspection contractors and weak contractual mechanisms*

Respondents claim that contractors performing the condition inspections minimize or neglect the importance of risk due to the lack of efficient risk knowledge skills. Furthermore, the contracts being addressed to these sorts of inspections lack rigid mechanism to enforce a risk-based approach. As a result, the data produced during condition inspections is not in line with risk-based principles.

Figure 16 shows the cause-effect tree of these perceptions. The tree can be also found in Appendix 3.

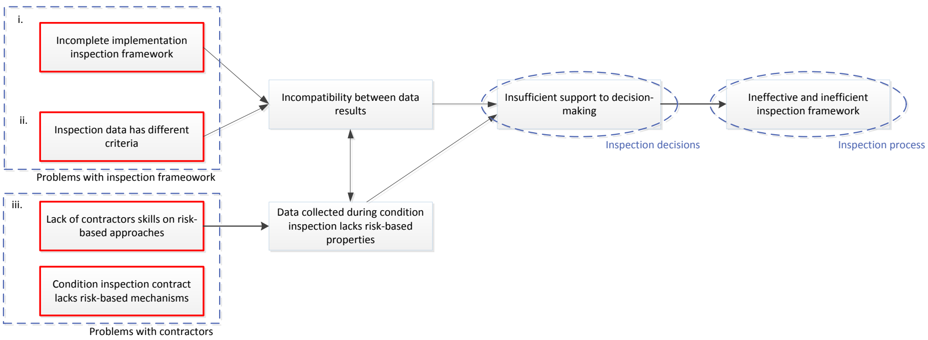


**Figure 16 – Cause-effect tree: problems with communication between inspection framework.**

### RECOMMENDED ACTIONS AS PERCEIVED BY PRACTICIONERS

- *Complete the implementation of the inspection framework*

Engineers defended that efforts should be made towards data integration between inspection types. To this end, the first recommendation goes to complete the implementation of inspection framework.

- *Introduce mechanisms to support condition inspection to perform a risk-based assessment*

Practitioners believe that data from *condition inspections* – namely, failure modes or degradation models - is vital to an efficient risk assessment of objects and their components. Thus, efforts must be done to improve the data integration between both inspection types. Practitioners mentioned that condition inspectors should be able to perform inspections based on risk, so that data can be used as an input to the maintenance inspection. This can be archived through contractual instruments that address risk-based procedures. The introduction of monitoring mechanisms over the contractors' performance (process) and over the inspection data that they provide (product) is also seen as a possible improvement.

### 4.5. Perceived DISK limitations and underused capabilities

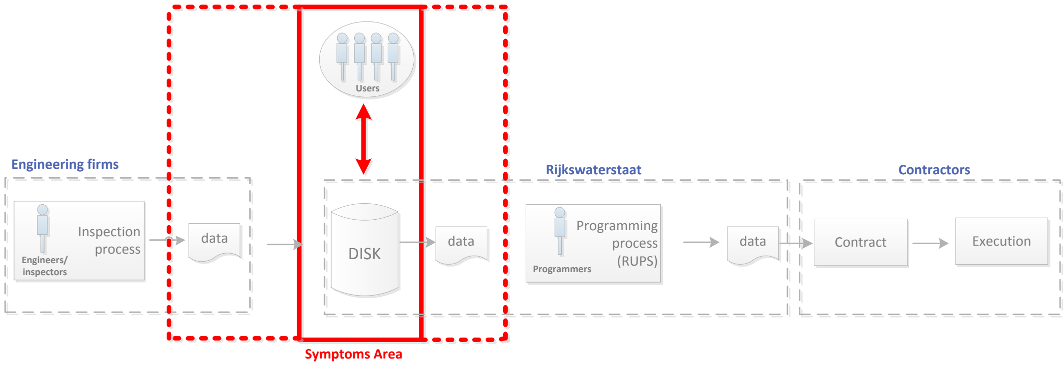


**Figure 17 – Perceived DISK limitation and underused capabilities: symptoms area in the maintenance management program.**

#### Symptoms

The role of DISK is highly recognized among practitioners. However, DISK tends to not be accepted and used in a similar way by all the practitioners. As a result, decisions are made by using different assumptions and by being support with distinct data. The following symptoms seem to be at the origin of this perception.

*i. Non-uniform DISK usage*

DISK is perceived as a static tool by lacking analytic procedures to support both the inspection and the programming processes. Thus, some practitioners seem to feel demotivated to interact with the tool, which in some cases can lead to the adoption of other database systems (duplication of data), to decentralized data inventory or can introduce complexities in data architecture. Such distinct behaviour on the data usage is believed to affect the effectiveness of decision outcomes.

*ii. DISK underused capabilities*

Practitioners tend to believe that DISK has capabilities that are not being optimally used. Among the capabilities referred, DISK is perceived as being underused specially for data and decision-making monitoring purposes. Among other examples, practitioners mentioned that DISK is not being used to control the measures implemented, to tackle risks and costs, to check current object performance or to determine the current level of network performance (PIN).

Practitioners mentioned that such underperformance affects the way data is used and as consequence, the quality of the maintenance management program.

Figure 18 shows the cause-effect tree of these perceptions. The tree can be also found in Appendix 3.

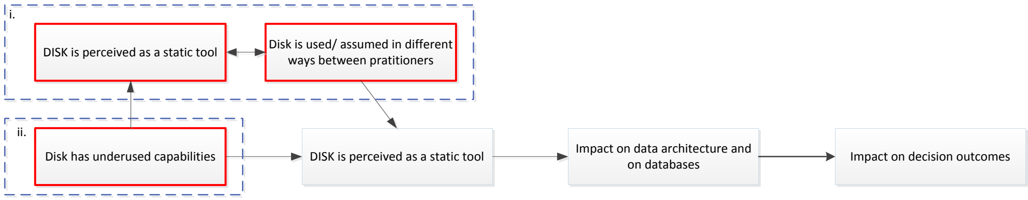


**Figure 18 – Cause-effect tree: perceived DISK limitations and underused capabilities.**

#### RECOMMENDED ACTIONS AS PERCEIVED BY PRACTICIONERS

Practitioners claimed that if the perceived difficulties were addressed to possible interventions, the effectiveness of the maintenance process would improve. Thus, they suggested some interventions.

- *Stimulate the use of DISK*

Stimulating the use of DISK is perceived as a relevant need. Respondents defended that such stimulus would contribute to minimize the existing gap between the ways that regional departments make decisions. Engineers remarked that a uniformed use of DISK through the regional departments is vital to reduce differences between knowledge-based. Thus, efforts towards the stimulation of DISK usage are perceived as important.

- *Address additional functions to DISK*

Practitioners suggested that RWS could make more value out of DISK by expanding its functionalities and supporting-services. Among the examples provided, it was said that DISK could be used for monitoring the maintenance measures that were programmed and procured to the market, including reference to the resulting risk involved. Also DISK should have updated input about the maintenance measures implemented. Moreover, it was mentioned that DISK could have a preliminary indication on the impact of the maintenance measures advised. For some practitioners it is vital to have a perception about the performance level achieved by adopting certain measures. Examples provided included reference to the level of RAMS criteria or simply to the performance indicators (PIN) of the network. Other suggestions include also the introduction of an information management system model, as it was mentioned before.

## 5.1. RESULTS

Data is a key enabler for any decision-making process.

The maintenance management program implemented in RWS is composed by several processes and involves large number participants. In such complex programs, the role of data, its properties and the manner it is used during the decision-making processes are vital aspects to the successful implementation of the program.

However, practitioners involved in the program have the perception that some challenges are affecting the efficiency and effectiveness of the program. As a result from the interviews, we identified those challenges by assembling the practitioners' symptoms in five main groups. To this end, we took into account the process that the challenges are affected to. Table 2 resumes the challenges identified during the interviews.

**Table 2 – Resume of the challenges perceived by practitioners and the respective process.**

| Challenges perceived | Process in the maintenance management program |
|---|---|
| Limited usefulness of the data management system to support the inspection process | Inspection and maintenance analysis |
| Limited usefulness of the data management system to support the programming process | Network maintenance programming |
| Problems with communication between maintenance management program processes | All the processes |
| Problems with the implementation of the inspection framework | Program and inspection framework |
| Perceived Disk limitations and underused capabilities | All the processes |

## 5.2. IDENTIFIED POTENTIAL FOR IMPROVEMENT

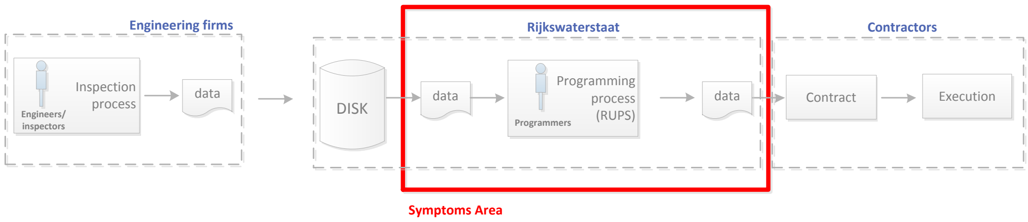


**Figure 19 – Limited usefulness of the data management system to support the programming process: symptoms area in the maintenance management program.**

From the challenges perceived by practitioners, it is visible that there is room for improvements within the existing program. We believe that all of these symptoms are relevant for the successful accomplishment of the maintenance management program. As matter of a fact, each process has a stake in the total program, which means that decisions and the respective data in early stages of the program have influence on the remaining processes.

As it is well known, it is our purpose to produce a design that minimizes the symptoms perceived. However, due to our project limitations, we consider relevant to narrow down our focus to the perceived internal symptoms. Thus, we would like to go further on the symptoms perceived by programmers (Figure 19): *limited usefulness of the data management system to support the programming process.* It is vital to remark that the remaining symptoms identified during the interviews are equally relevant and must be addressed to further research.

#### *Motivation*

Due to economic pressures to reduce spending on maintenance, the budget available for maintenance activities is gradually reducing. Therefore, the budget available to each region is not enough to implement all the advised measures. Such limitations ask the regional departments to adopt some criteria to supports the allocation of maintenance measures in a cost-effective manner.

Under these circumstances, it is the ambition of RWS to support programmers towards a risk-based maintenance programming. To achieve this goal, it is vital that programmers have a good understanding on the risk involved in the objects though good data.

However, programmers seem to face difficulties on understanding the risk concept, which leads us to believe that RWS might not be translating data (from DISK to RUPS) in an optimal way. Considering the symptoms presented by programmers, it seems that vital data to the programming is difficult to find or is not clearly organized or presented. Currently, data from DISK to RUPS seems to be very much focused on maintenance measures and costs and the emphasis on risk assessment is still far from ideal. It is the goal of RWS to support the output of DISK in a proper way in order to make the programming more effective.

To solve these symptoms, we propose to develop a tool that provides support to programmers to make better decisions towards a risk-based maintenance. This involves not just the translation of the right data from DISK to RUPS, but also a good understanding of risk concepts. While the direct contribution of the proposed design tool is to improve the way inspection data is translated (or delivered) to the programming process, the indirect benefits are:

- To raise awareness on practitioners about the need to move towards a risk-based management approach.
- To improve the efficiency and the overall effectiveness of the programming decision-making (i.e. define cost-effective maintenance measures);
- To provide reliable maintenance execution projects to the execution market parties based on risk approach.

### 5.3. Further prospects

This study will be followed by a set of procedures:

- Approve the design proposal;
- Define the quality criteria to addressed to the design product;
- Design the tool;

- Test and implement the tool.

### 5.4. Acknowledgement

The author would like to thank all the practitioners who participated in this study.

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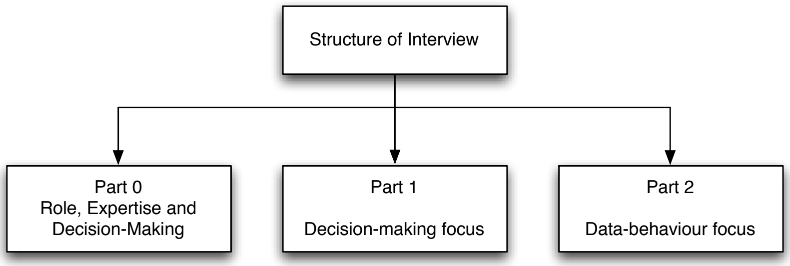
## INTERVIEW PROTOCOL. GUIDELINES.

### 1. Field study: Maintenance and Inspection decision-making in Rijkswaterstaat.

The purposes of this interview are based in a descriptive and a normative approach. In a **descriptive approach** we aim to characterize the current situation by assessing the perception of decision-makers regarding data characteristics or behaviours, and decision outcomes. Simultaneously, under the context of a **normative approach**, we aim to assess 'ideal' characteristics or behaviours, as perceived by those individuals.

### 2. Structure of Interview.

The interview is organized in three sections, as it follows:



| | | |
|---|---|---|
| RESPONDENT NAME | | |
| ORGANIZATION | | |
| DECISION PROCESS | | |
| DATE | TIME | No. |

## PART 0. PROFESSIONAL ROLE, EXPERTISE AND IDENTIFICATION OF DECISION PROCESS.

Q0. Introduction. Professional role and identification of decision process.

- What are your current position and your level of expertise? What are your responsibilities towards Rijkswaterstaat?
- What is the decision-process you are involved in? Can you briefly describe the decision process?

## PART 1. DECISION-MAKING FOCUS.

### 1.1. CHARACTERISTICS OF DECISION-MAKING.

Q1. Decision objectives.

- How do you perceive the goals of the decision process? In your opinion what are the main decision goals?

Q2. Quality of current decision.

- Focusing on the current decision outcomes, how do you perceive the quality of the decision? How 'good' are the decision outcomes?

Q3. Decision *issues.*

- What are the *issues* affecting the quality of the decision? What is decision *uncertain* about?
    - Why did you come to this perception?
- How often do you deal with these issues during a decision process?
    - Can you describe a situation, or give an example(s)?

Q4. Decision *sources.*

- What are the causes (or sources) of those *issues* (or uncertainties)?
    - Why did you come to this perception?

Q5. Consequences of *issues* and *sources.*

- What are the possible consequences of those *issues* (or uncertainties)?
    - Why did you come to this perception?
    - If applicable, can you describe a situation, or give an example(s)?

### 1.2. MANAGEMENT OF UNCERTAINTIES.

Q6. Strategies used to handle decision-making (behaviour).

- What strategies are already used to manage sources of *issues* (or uncertainties)?

- What criteria is used to the selection of a specific strategy?

### 1.3. Decision-values.

Q7. Characteristics of an efficient decision.

- In an 'ideal' situation, what characteristics (or properties) should those decisions have?
- How should a decision be made? What requisites (criteria, or conditions) should the decision process fulfil to ensure those characteristics?

## Part 2. Data-behaviour focus.

### 2.1. Characteristics of Data Quality.

Q8. Perceived importance of data to the decision process and respective characteristics.

- Which data are considered important to achieve the decision goals?
    - Why did you come to this perception?

Q9. Perceived (existing) characteristics in data.

- How are those characteristics present in data (*format and content*)? How are these characteristics reflected in current *data*?
    - Why did you come to this perception?

Q10. Perceived causes (or influences) on data characteristics.

- What are the causes of problems (or influences) on existing data used?
    - Why did you come to this perception?

Q11. Perceived consequences of existing data characteristics.

- What are possible consequences of existing characteristics of data on the outcomes of the decision?
    - Why did you come to this perception?

### 2.2. Management of data Uncertainties.

Q12. Strategies used to handle data usage (behaviour).

- What strategies are already used to manage sources of issues (or uncertainties)?
- What criteria is used to the selection of a specific strategy?

### 2.3. Decision-values.

Q13. Perceived 'ideal' data and 'ideal' characteristics of data.

- Which other or different data would be needed to achieve the goals of a decision?
    - Why did you come to this perception?
- What characteristics should all data (existing and non-ex) have?
    - Why did you come to this perception?

### 2.3. AREAS OF IMPROVEMENT.

Q14. Identification of possible areas of improvement in the DISK database.

- In your opinion, do you consider any possibility to make greater or better use of the DISK database? Which areas? Can you give examples?

### Rijkswaterstaat Regional: Programming

| Order | Interviewee | Regional Department | Date of Interview |
|---|---|---|---|
| P1 | Wouter Geudeke | Utrecht | 06.12.2013 |
| P2 | Michel Jansen | Oost-Nederland (Arnhem) | 10.12.2013 |
| P3 | Marco Buiting & Wim Engbers | Oost-Nederland (Hengelo) | 16.01.2014 |
| P4 | Gerard Ras | Noord-Holland (Ijmuiden) | 24.01.2014 |
| P5 | Karin Ruimen | Limburg (Roermond/Maastricht) | 28.01.2014 |
| P6 | Menno Nagelhout & Anno van Dijke | Zeeland (Goes) | 31.01.2014 |
| P7 | Klaas Koning | Friesland (Grou) | 26.02.2014 |
| R1 | Johan Kramer | RWS Central | 23.01.2014 |

### Rijkswaterstaat Central

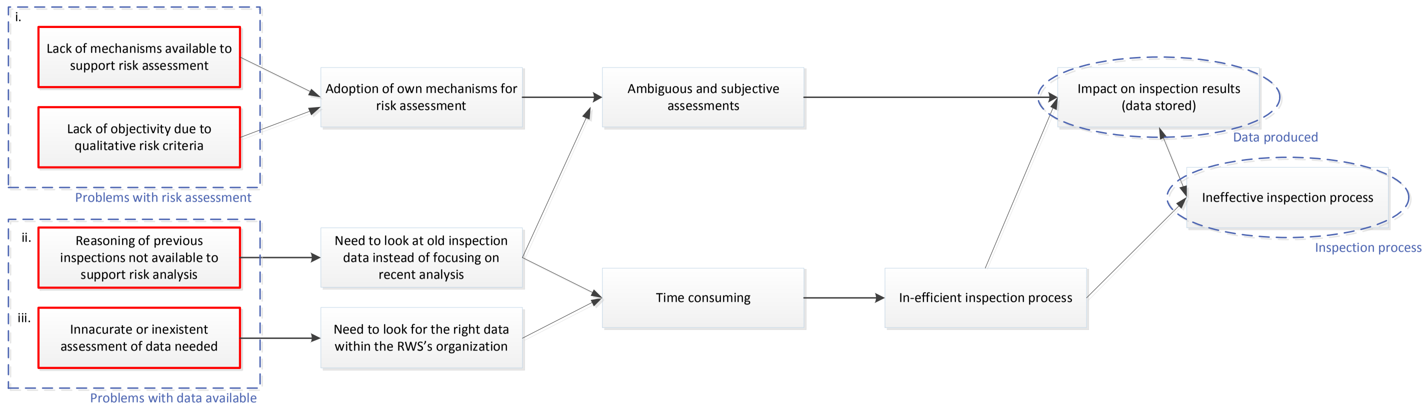
| Order | Interviewee | Date of Interview |
|---|---|---|
| R2 | Nico Booij | 27.01.2014 |
| R3 | Rindert van Dalen | 07.02.2014 |
| R4 | Jan-Willem van Berghem | 25.02.2014 |

### Engineering Firms (Inspectors)

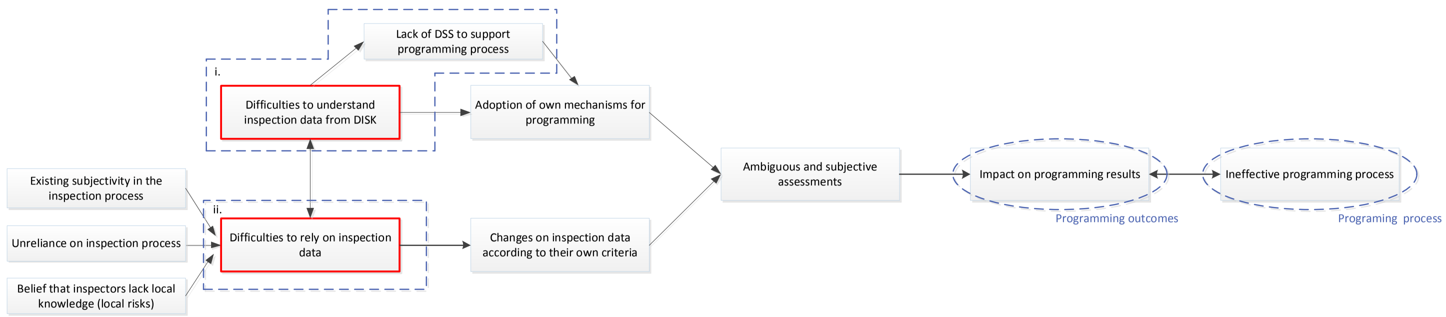
| Order | Interviewee | Firm | Date of Interview |
|---|---|---|---|
| I1 | Michel Post & Govert van Meerkerk | Nebest | 30.01.2014 |
| I2 | Bas de Ruiter | IV-Infra | 28.02.2014 |
| I3 | Bart Mante & Alex | RoyalHaskoning DHV | 06.03.2014 |

18 participants in 14 interviews

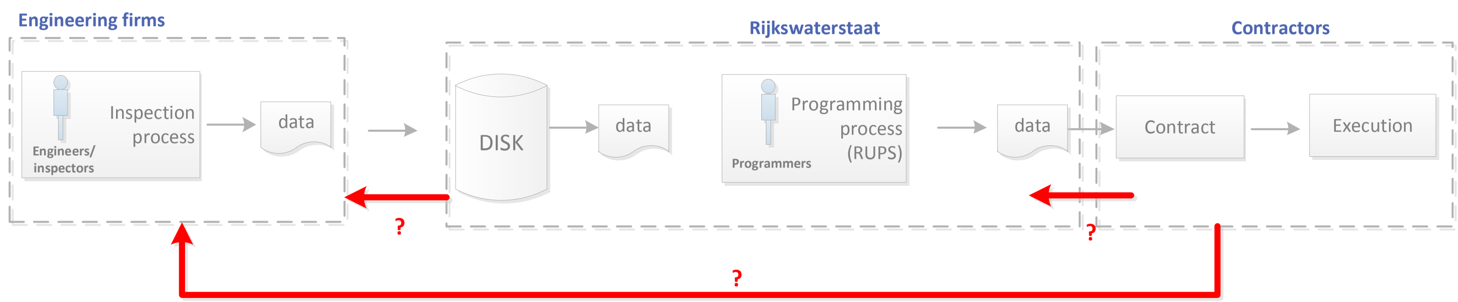
- **Limited usefulness of the data management system to support the inspection process.**



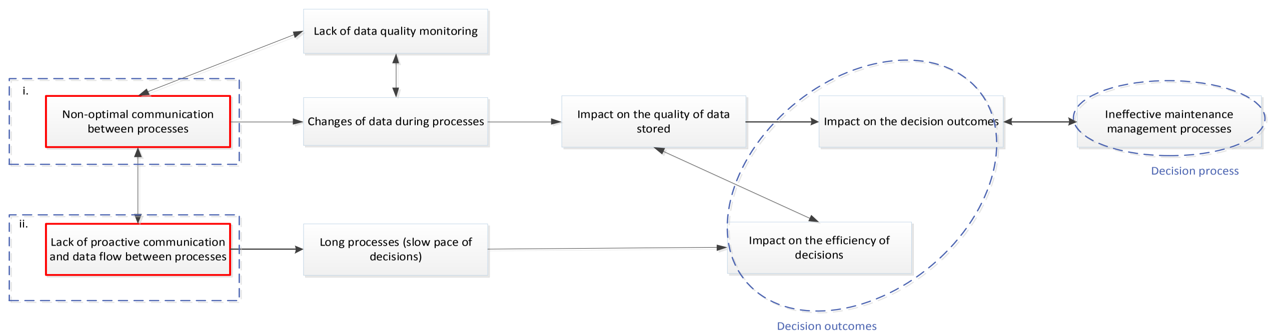
- **Limited usefulness of the data management system to support the programming process.**



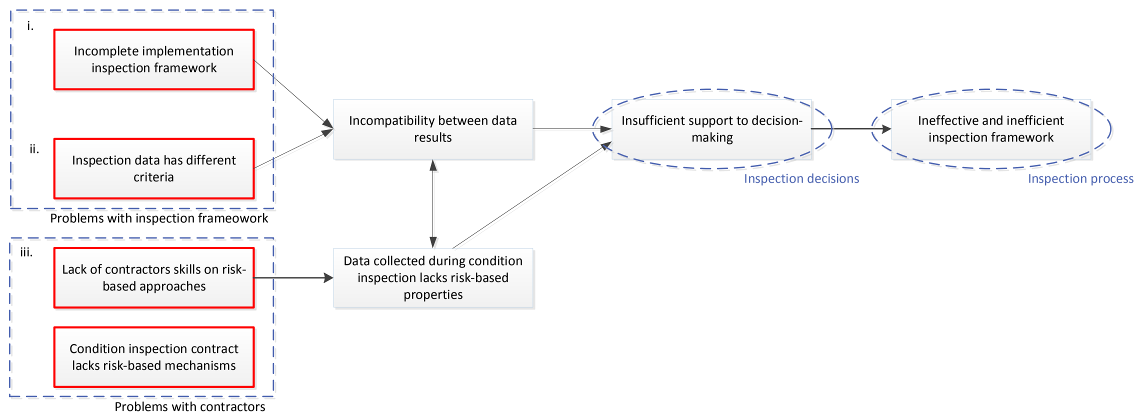

- **Perceived problems with communication between processes.**



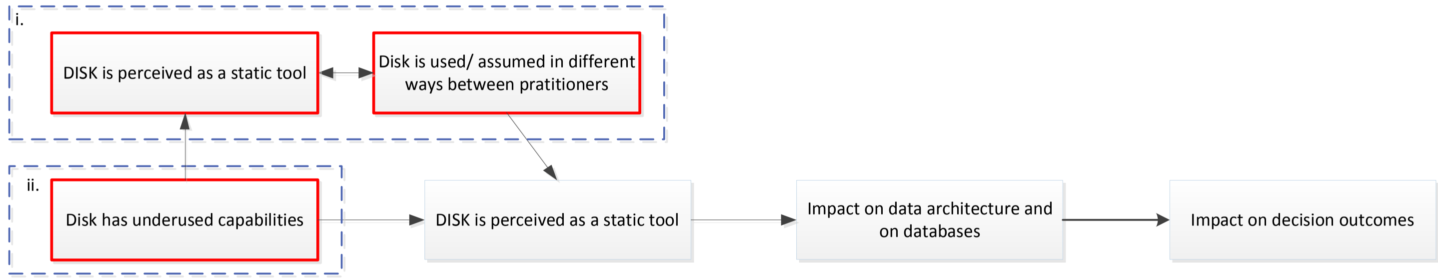
- **Problems with communication between maintenance management processes.**




- **Problems with communication between inspection framework**



- **Perceived DISK limitations and underused capabilities.**



# APPENDIX 4

# RAMS MODEL

*Number of pages: 8*

# PART 0. SYSTEM CHARACTERISATION

**DATA INPUT**

| GENERIC | SPECIFIC |
|---|---|
| Inventory data | |
| Design data | |
| Maintenance Plan (IHP) | |
| Internal reference documents: RBO/ BON | |

**BLOCK 0. SYSTEM CHARACTERISATION AND PERFORMANCE LIMITS**

## PART 0. SYSTEM CHARACTERISATION: PROCEDURES

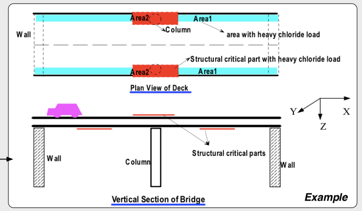
### 0.1 STRUCTURAL CHARACTERISATION

#### 0.1.1 Structural decomposition

Object breakdown structure in Structural/ Functional Units (i.e. distribution of elementary units).

#### 0.1.2 Structure element criticality

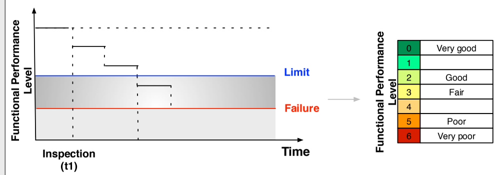
Criticality ssessment of Structural/ Functional Units.




### 0.2 LIMITS FOR FUNCTIONAL PERFORMANCE

#### 0.2.1 Functional performance threshold

Define the critical functional performance level(s) as the minimum value allowed for each Structural/ Functional Unit.



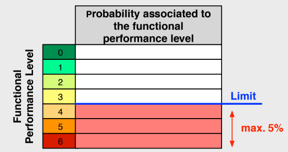

Simplified deterioration model of an element without maintenance action (left) and functional performance grading scheme based on qualitative judgment (right)

#### 0.2.2 Target probability for critical functional performance level

Define the target probability for critical functional performance level, as the limit probability accepted for the functional performance of each Structural/ Functional Unit.

***Example***

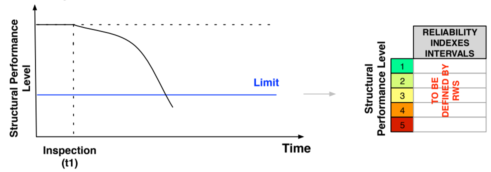
*Assumptions:*
*-> Critical functional performance level: between levels 3 and 4 (from 0.2.1)*
*-> Acceptable probability: < 5%*




### 0.3 LIMITS FOR STRUCTURAL PERFORMANCE

#### 0.3.1 Structural performance threshold

Define the critical reliability performance level as the minimum reliability value allowed for each Structural/ Functional Unit.



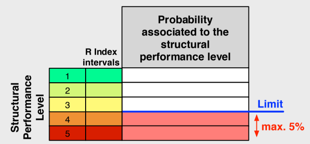

Simplified structural performance profile of an item without maintenance action (left) and grading system to assess it based on intervals of Reliability Index Intervals (right)

#### 0.3.2 Target probability for critical structural performance level

Define the target probability for critical structural performance level, as the limit probability accepted for the structural performance of each Structural/ Functional Unit.

***Example***

*Assumptions:*
*-> Critical structural performance level: between levels 3 and 4 (from 0.3.1)*
*-> Acceptable probability: < 5%*



# PART 1. RISK ASSESSMENT ON THE ELEMENT LEVEL

## DATA INPUT

### GENERIC

- Inventory data
- Design data
- Inspection history
- Maintenance history
- Maintenance Plan (IHP)
- Internal reference documents: RBO/ BON
- **Block 0.**

### SPECIFIC

- Design assumptions
  - underlying code
  - new code
- Loading
  - current traffic load
  - predictable load progression
- Load modelling
- Time-variant reliability models
- Climate/ environmental features
- Condition State
- Material tests
- Dynamic measurements

## PART 1. RISK ASSESSMENT ON ELEMENT LEVEL: PROCEDURES

**BLOCK I.**
**RELIABILITY ASSESSMENT (NO MAINTENANCE ACTION)**

### I.1 CURRENT SERVICEABILITY PROFILE

#### I.1.1 Deterioration mechanisms

**Based on the inspection performed, identify the existing deterioration mechanisms and the underlying causes for those mechanisms.**

#### I.1.2 Probability range of functional performance Levels

**For each Structural/ Functional Unit, determine the current probability range of functional performance levels based on the grading scheme defined in block 0.2.1.**

*Example*

| Functional Performance Level | Probability associated to the functional performance level |
|---|---|
| 0 | |
| 1 | |
| 2 | |
| 3 | 95% |
| 4 | 5% |
| 5 | |
| 6 | |

### I.2 PREDICTED SERVICEABILITY PROFILE

**Based on the current serviceability profile, estimate the probability range of functional performance Levels for each Structural/ Functional Unit for the next 10 year assuming no maintenance action.**

*Example*

| Functional Performance Level | Probability associated to the functional performance level: CURRENT | PREDICTED |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | 95% | 90% |
| 4 | 5% | 10% |
| 5 | | |
| 6 | | |

### I.3 ANALYSIS OF SERVICEABILITY PROFILE

**Compare the probabilities assessed (current and predicted) with the acceptable probability for critical functional performance level(s) as it is defined in block 0.2.**

*Example*

*Assumptions:*
*-> CCL: between levels 3 and 4 (from 0.2.1)*
*-> Acceptable probability: < 5% (from 0.2.2)*

| Functional Performance Level | Probability associated to the functional performance level: CURRENT | PREDICTED |
|---|---|---|
| 0 | | |
| 1 | | |
| 2 | | |
| 3 | 100% | 90% |
| 4 | | 10% |
| 5 | | |
| 6 | | |

Limit

### I.4 DECISION-SUPPORT BOX I

Are the probabilities to reach a critical functional performance Level (i.e. current and/ or predicted) higher than the target defined by RWS in Block 0.2?
- YES → Is the structural/functional unit under analysis critical** to the structure?
- NO → Are the current load(s) and/or benchmark values* like to change substantially in the next 10 years?

Are the current load(s) and/or benchmark values* like to change substantially in the next 10 years?
- YES → Is the structural/functional unit under analysis critical** to the structure?
- NO → Do you want to determine the remaining service life of the structure?

Is the structural/functional unit under analysis critical** to the structure?
- YES → Reliability-based assessment (i.e. reliability analysis and service life) is advised. **Go to BLOCK I.5**
- NO → Do you want to determine the remaining service life of the structure?

Do you want to determine the remaining service life of the structure?
- YES → Reliability-based assessment (i.e. reliability analysis and service life) is advised. **Go to BLOCK I.5**
- NO → Maintenance actions might not be needed on element Level; nevertheless, ... **Go to BLOCK II**

* Benchmark values are those values established by functional or structural designing references or safety standards or protocols. Examples are national or international codes or regulations, climate/ environment limits or chemical exposure limits.

** A structural/ functional unit is considered critical if it compromises the structural/ functional safety of the object (see Block 0.1). For the sake of this model, RWS must define the target criticality of each element.

## DATA INPUT

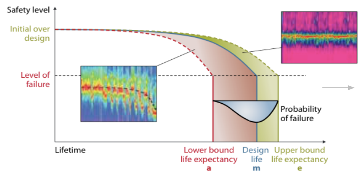
| GENERIC | SPECIFIC |
|---|---|
| Inventory data | |
| Design data | Design assumptions<br>- underlying code<br>- new code |
| | Loading<br>- current traffic load<br>- predictable load progression |
| | Load modelling |
| | Time-variant reliability models |
| | Climate/ environmental features |
| Inspection history | Condition State |
| | Material tests |
| | Dynamic measurements |
| Maintenance history | |
| Maintenance Plan (IHP) | |
| Internal reference documents: RBO/ BON | |
| **Block 0.** | |

## BLOCK I. RELIABILITY ASSESSMENT (NO MAINTENANCE ACTION)

### I.5 CURRENT AND PREDICTED STRUCTURAL RELIABILITY PROFILE

#### I.5.1 Current and predicted structural (reliability) profile

**For the critical limit level violation, determine the current reliability level (in probabilistic terms) and predict them for the period ahead of 10 years assuming no maintenance action.**




| Structural Performance Level | Probability associated to structural performance level |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |

CURRENT: Minimum assessed value of ß1 → Minimum ß1 associated to the main structure

IN 10 YEAR TIME: Minimum assessed value of ß1 → Minimum ß1 associated to the main structure

**Conceptual scheme of the probabilistic model based on Wenzel et al. (2012) (left) and scheme of reliability assessments (right).**

#### I.5.2 Remaining service life

**Determine the remaining service life of the element (in probabilistic terms) assuming no maintenance action.**

| | PROBABILISTIC LIFE EXPECTANCY |
|---|---|
| Lower bound life expectancy | X years |
| Design life | Y years |
| Upper bound life expectancy | Z years |

### I.6 ANALYSIS OF RELIABILITY PROFILE

**Compare the probabilities assessed (current and predicted) with the acceptable probability for critical structural performance level(s) as it is defined in blcok 0.3.**

***Example***

*Assumptions:*
*-> CRL: between Level 3 and 4* *(from 0.3.1)*
*-> Acceptable probability: < 5%* *(from 0.3.2)*

| Structural Performance Level | PROBABILITY ASSOCIATED TO THE STRUCTURAL PERFORMANCE LEVEL: CURRENT | PREDICTED |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | 95% | 90% |
| 4 | 5% | 10% |
| 5 | | |

Limit

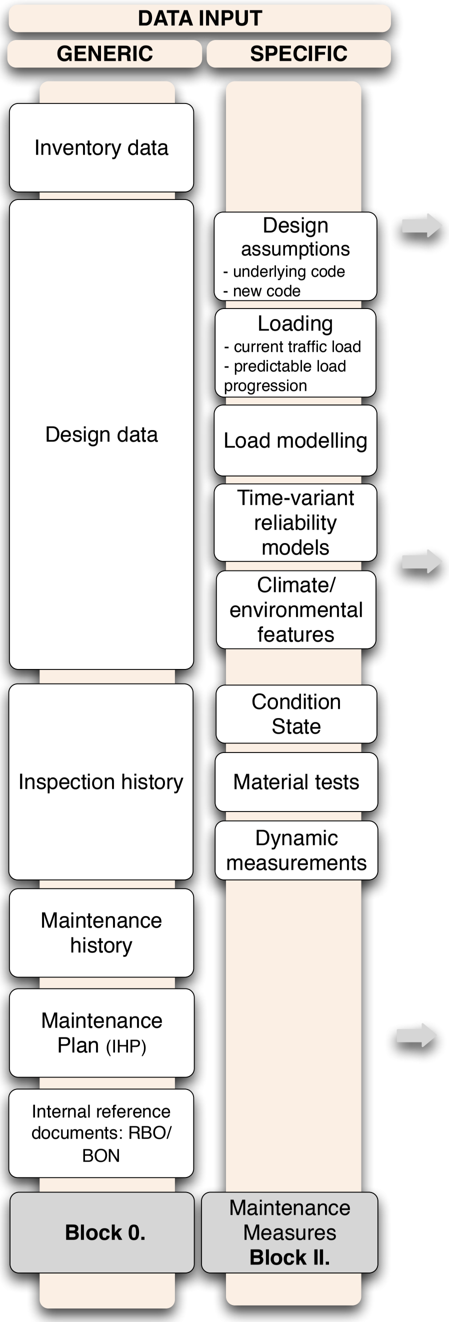
## BLOCK II. MAINTENANCE ACTIONS

### II.1 MAINTENANCE ACTIONS

**For each Structural/ Functional Unit, define and characterise the maintenance actions to be applied during the period ahead of 10 years.**
**Define at least two maintenance actions.**

The default option is: *do-nothing*

| UNIT | MAINTENANCE ACTIONS | TIME OF FIRST APPLICATION | TIME OF SUBSEQUENT APPLICATION |
|---|---|---|---|
| ELEMENT | Do-nothing | - | - |
| | Action 1 | year | year |
| | Action *n* | year | year |




## BLOCK III. RELIABILITY ASSESSMENT (UNDER MAINTENANCE ACTION)

### III.1 DECISION-SUPPORT BOX II

Is a reliability-based assessment performed from block II?

- NO → Evaluate the effects of maintenance actions on the functional performance profile. **Go to BLOCK III.2**
- YES → Evaluate the effects of maintenance actions on the structural performance profile. **Go to BLOCK III.3**

### III.2 EFFECTS OF MAINTENANCE ACTIONS ON THE FUNTIONAL PERFORMANCE PROFILE

#### II.2.1 Effects on functional performance profile under maintenance actions

**For each Structural/ Functional Unit, evaluate the effects of each maintenance action on the functional performance profile (in terms of probability range) for the period ahead of 10 years.**

***Example***

Expected Functional performance Improvement

| Functional performance level | Current Functional performance Level | Predicted Functional performance (No maintenance action) | Predicted Functional performance (W. maintenance action) |
|---|---|---|---|
| 0 | | | |
| 1 | | | |
| 2 | 30% | 10% | 30% |
| 3 | 65% | 80% | 70% |
| 4 | 5% | 10% | |
| 5 | | | |
| 6 | | | |

Limit

### III.3 EFFECTS OF MAINTENANCE ACTIONS ON THE STRUCTURAL PERFORMANCE PROFILE

#### III.3.1 Effects on structural performance profile under maintenance actions

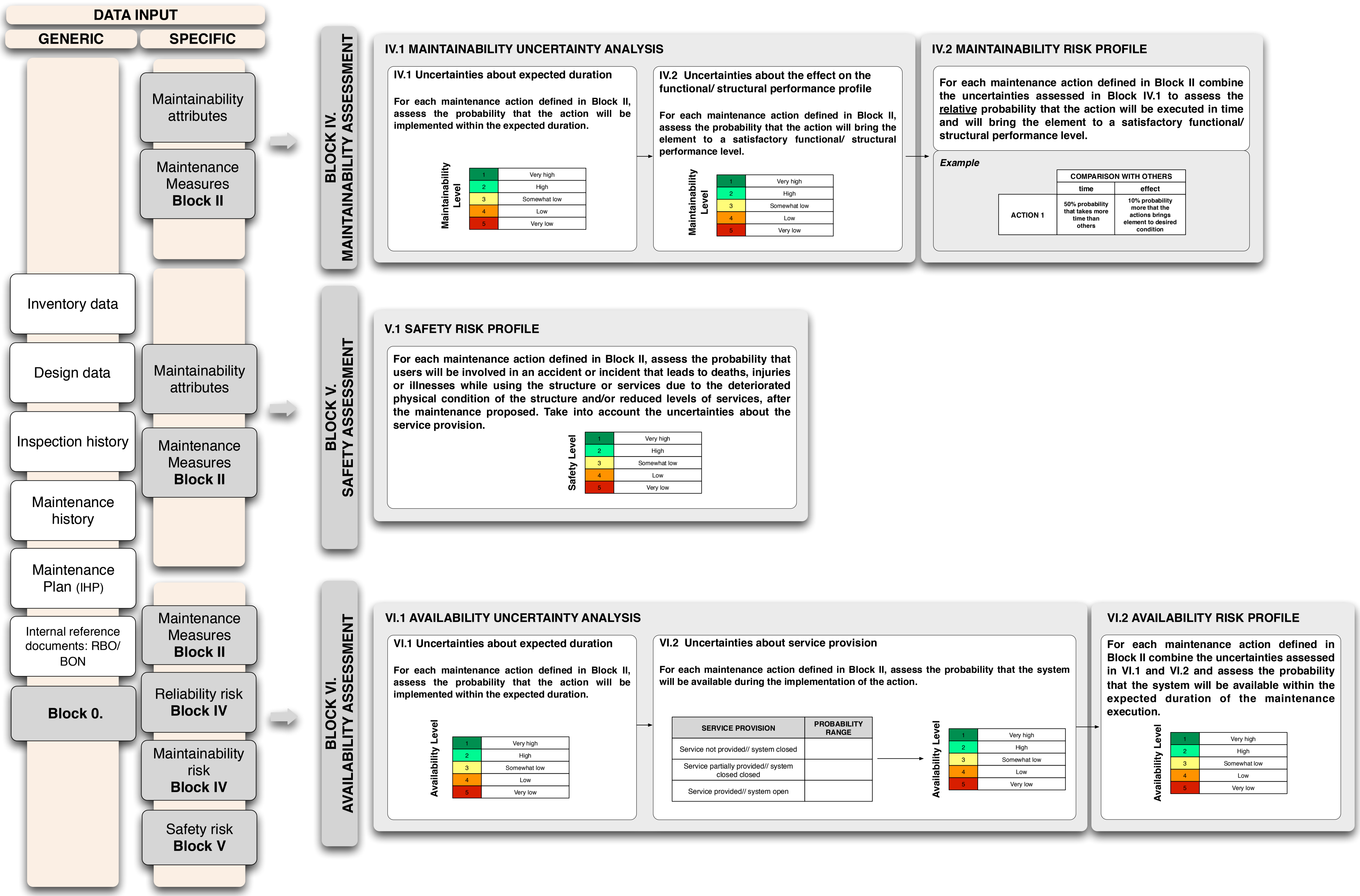
**For each Structural/ Functional Unit, evaluate the effects of each maintenance action on the structural performance profile (in terms of probability range) for the period ahead of 10 years.**

***Example***

Expected Reliability Improvement

| Structural performance level | Current Reliability Level | Predicted reliability (No maintenance action) | Predicted reliability (W. maintenance action) |
|---|---|---|---|
| 1 | | | |
| 2 | 30% | 10% | 70% |
| 3 | 65% | 80% | 30% |
| 4 | | | |
| 5 | | | |

Limit



DATA INPUT
GENERIC
SPECIFIC
Inventory data
Design data
Inspection history
Maintenance history
Maintenance Plan (IHP)
Internal reference documents: RBO/ BON
Block 0.
Maintainability attributes
Maintenance Measures Block II
Maintainability attributes
Maintenance Measures Block II
Maintenance Measures Block II
Reliability risk Block IV
Maintainability risk Block IV
Safety risk Block V
BLOCK IV. MAINTAINABILITY ASSESSMENT
IV.1 MAINTAINABILITY UNCERTAINTY ANALYSIS
IV.1 Uncertainties about expected duration
For each maintenance action defined in Block II, assess the probability that the action will be implemented within the expected duration.
Maintainability Level
1 Very high
2 High
3 Somewhat low
4 Low
5 Very low
IV.2 Uncertainties about the effect on the functional/ structural performance profile
For each maintenance action defined in Block II, assess the probability that the action will bring the element to a satisfactory functional/ structural performance level.
Maintainability Level
1 Very high
2 High
3 Somewhat low
4 Low
5 Very low
IV.2 MAINTAINABILITY RISK PROFILE
For each maintenance action defined in Block II combine the uncertainties assessed in Block IV.1 to assess the relative probability that the action will be executed in time and will bring the element to a satisfactory functional/ structural performance level.
Example
COMPARISON WITH OTHERS
time
effect
ACTION 1
50% probability that takes more time than others
10% probability more that the actions brings element to desired condition
BLOCK V. SAFETY ASSESSMENT
V.1 SAFETY RISK PROFILE
For each maintenance action defined in Block II, assess the probability that users will be involved in an accident or incident that leads to deaths, injuries or illnesses while using the structure or services due to the deteriorated physical condition of the structure and/or reduced levels of services, after the maintenance proposed. Take into account the uncertainties about the service provision.
Safety Level
1 Very high
2 High
3 Somewhat low
4 Low
5 Very low
BLOCK VI. AVAILABILITY ASSESSMENT
VI.1 AVAILABILITY UNCERTAINTY ANALYSIS
VI.1 Uncertainties about expected duration
For each maintenance action defined in Block II, assess the probability that the action will be implemented within the expected duration.
Availability Level
1 Very high
2 High
3 Somewhat low
4 Low
5 Very low
VI.2 Uncertainties about service provision
For each maintenance action defined in Block II, assess the probability that the system will be available during the implementation of the action.
SERVICE PROVISION
PROBABILITY RANGE
Service not provided// system closed
Service partially provided// system closed closed
Service provided// system open
Availability Level
1 Very high
2 High
3 Somewhat low
4 Low
5 Very low
VI.2 AVAILABILITY RISK PROFILE
For each maintenance action defined in Block II combine the uncertainties assessed in VI.1 and VI.2 and assess the probability that the system will be available within the expected duration of the maintenance execution.
Availability Level
1 Very high
2 High
3 Somewhat low
4 Low
5 Very low

# PART 2. RISK ASSESSMENT ON THE STRUCTURE LEVEL

## DATA INPUT

**GENERIC**

- Inventory data
- Design data
- Inspection history
- Maintenance history
- Maintenance Plan (IHP)
- Internal reference documents: RBO/ BON

**SPECIFIC**

- Maintenance Measures **Block II**
- Risk Profiles on R-M-S-A **Blocks I, III, IV, V & VI**
- Maintenance Strategies **Block VII**
- Risk Profiles on M-A **Blocks IV & VI**

## PART 2. RISK ASSESSMENT ON STRUCTURE LEVEL: PROCEDURES

### BLOCK VII. MAINTENANCE STRATEGIES

**VII.1 MAINTENANCE STRATEGY**

Based on the maintenance actions defined in Block III and on the multiple risk profiles defined on the element level, define and characterise at least two maintenance strategies to be applied during the period ahead of 10 years.

| | MAINTENANCE ACTIONS | | | | RISK PROFILES (ELEMENT LEVEL) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | BLOCK II | | | | BLOCKS I & III | | BLOCK IV | BLOCK V | BLOCK VI |
| | ACTION | TIME OF FIRST APPLICATION | TIME OF SUBSEQUENT APPLICATION | EXPECTED DURATION FOR EXECUTION | RELIABILITY RISK PROFILE (NO MAINTENANCE) | RELIABILITY RISK PROFILE (UNDER MAINTENANCE) | MAINTAINABILITY RISK PROFILE | SAFETY RISK PROFILE | AVAILABILITY RISK PROFILE |
| MAINTENANCE STRATEGY 1 | Unit 1: Do-nothing | - | - | - | | | | | |
| | Unit 2: Action a | year | year | days/months | | | | | |
| | Unit 3: Action b | year | year | days/months | | | | | |
| MAINTENANCE STRATEGY 2 | Unit 1: Do-nothing | - | - | - | | | | | |
| | Unit 2: Action a | year | year | days/months | | | | | |
| | Unit 3: Action b | year | year | days/months | | | | | |

### BLOCK VIII. AVAILABILITY ASSESSMENT

**VIII.1 AVAILABILITY UNCERTAINTY ANALYSIS**

**VIII.1 Uncertainties about expected duration**

For each maintenance strategy defined in Block VII, assess the probability that the actions will be implemented within the expected duration of the strategy.

Availability Level

| | |
|---|---|
| 1 | Very high |
| 2 | High |
| 3 | Somewhat low |
| 4 | Low |
| 5 | Very low |

**VIII.2 Uncertainties about service provision**

For each maintenance strategy defined in Block VII, assess the probability that the system will be available within the implementation of the strategy.

| SERVICE PROVISION | PROBABILITY RANGE |
|---|---|
| Service not provided// system closed | |
| Service partially provided// system closed closed | |
| Service provided// system open | |

Availability Level

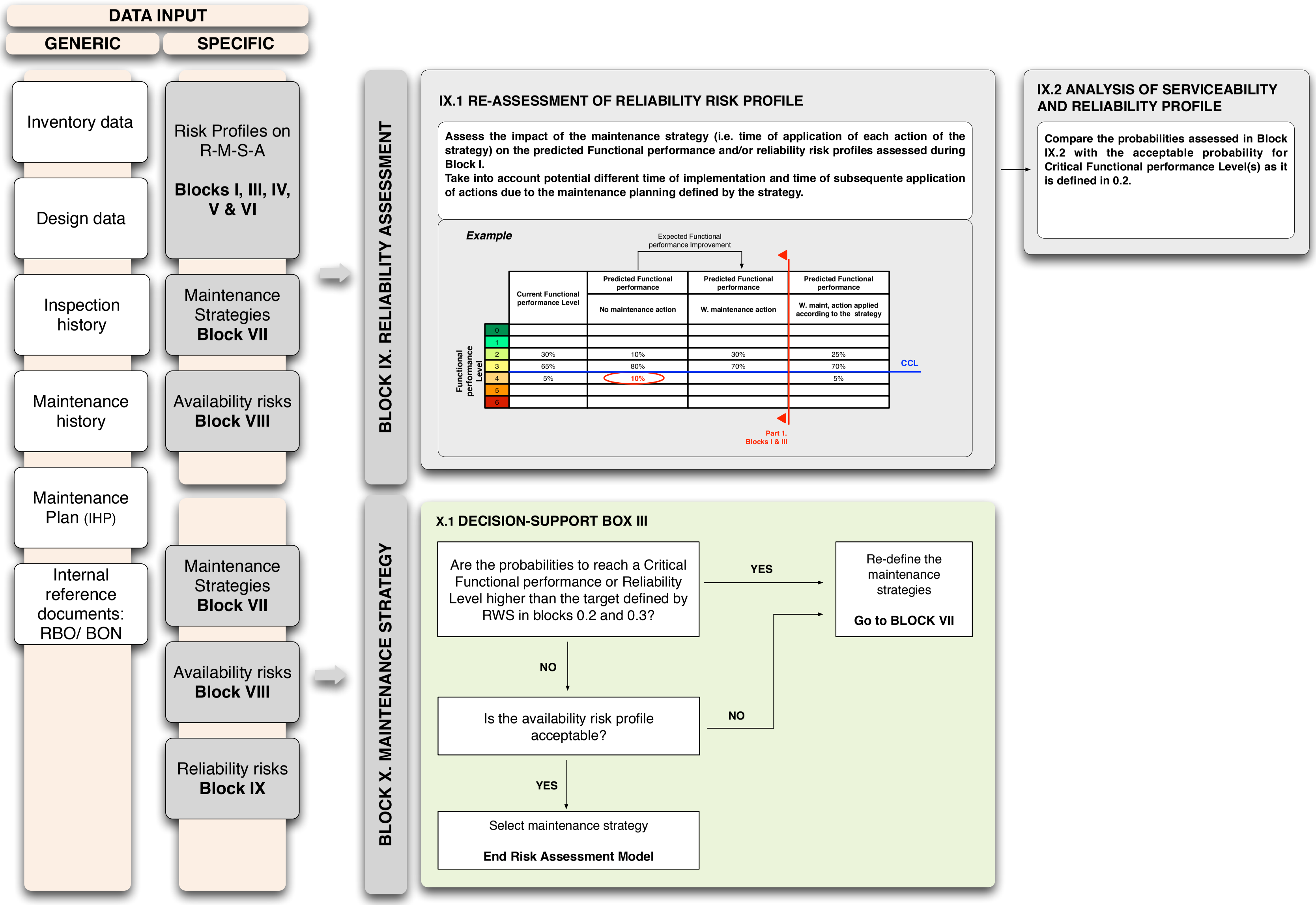
| | |
|---|---|
| 1 | Very high |
| 2 | High |
| 3 | Somewhat low |
| 4 | Low |
| 5 | Very low |

**VIII.2 AVAILABILITY RISK PROFILE**

For each maintenance strategy defined in Block VII, combine the uncertainties assessed in VIII.1 and VIII.2 and assess the probability that the system will be available within the expected duration of the maintenance strategy.

Availability Level

| | |
|---|---|
| 1 | Very high |
| 2 | High |
| 3 | Somewhat low |
| 4 | Low |
| 5 | Very low |


DATA INPUT
GENERIC
SPECIFIC
Inventory data
Design data
Inspection history
Maintenance history
Maintenance Plan (IHP)
Internal reference documents: RBO/ BON
Risk Profiles on R-M-S-A
Blocks I, III, IV, V & VI
Maintenance Strategies Block VII
Availability risks Block VIII
Maintenance Strategies Block VII
Availability risks Block VIII
Reliability risks Block IX
BLOCK IX. RELIABILITY ASSESSMENT
IX.1 RE-ASSESSMENT OF RELIABILITY RISK PROFILE
Assess the impact of the maintenance strategy (i.e. time of application of each action of the strategy) on the predicted Functional performance and/or reliability risk profiles assessed during Block I.
Take into account potential different time of implementation and time of subsequente application of actions due to the maintenance planning defined by the strategy.
Example
Expected Functional performance Improvement
Current Functional performance Level
Predicted Functional performance
No maintenance action
Predicted Functional performance
W. maintenance action
Predicted Functional performance
W. maint, action applied according to the strategy
Functional performance Level
30%
65%
5%
10%
80%
10%
30%
70%
25%
70%
5%
CCL
Part 1. Blocks I & III
IX.2 ANALYSIS OF SERVICEABILITY AND RELIABILITY PROFILE
Compare the probabilities assessed in Block IX.2 with the acceptable probability for Critical Functional performance Level(s) as it is defined in 0.2.
BLOCK X. MAINTENANCE STRATEGY
X.1 DECISION-SUPPORT BOX III
Are the probabilities to reach a Critical Functional performance or Reliability Level higher than the target defined by RWS in blocks 0.2 and 0.3?
YES
Re-define the maintenance strategies
Go to BLOCK VII
NO
Is the availability risk profile acceptable?
NO
YES
Select maintenance strategy
End Risk Assessment Model

## APPENDIX 5

## LIST OF POTENTIAL MAINTAINABILITY ATTRIBUTES

*Number of pages: 1*

**MAINTAINABILITY ATTRIBUTES FOR AVAILABILITY**

| GROUP | CODE | ATTRIBUTE | DEFINITION FROM LITERATURE | SYSTEM CONTRIBUTING FEATURES |
|---|---|---|---|---|
| DESIGN | D1 | Accessibility | Degree of ease with which it is possible to reach a certain location from other locations. It measures the ability of a element to be accessible by worker. | It will be checked:<br>* the existing stairs or plataforms to access the element without using external equipments or tools. |
| | D2 | Assembly/disassembly | Ability to remove or replace components from an element (or item). | It will be checked the existing types of connection between the elements, such as:<br>* weldings<br>* joints<br>* connections<br>* cast-in situ |
| LOGISTICS SUPPORT | L1 | Personnel organization | Amount of people required to carry out the maintenance action | It will be checked:<br>* the amount of people estimated per maintenance action<br>* the possible division of task into concurrent tasks (active maintenance time) |
| | L2 | Tools and equipments | Requirements in terms of tools and equipments needed for the maintenane action by taking into account functionality, ergonomics and acquisition easiness. | It will be checked:<br>* the type of tools and equipments needed to the work<br>* degree of standardization of components and tools |
| | L3 | Materials and spare parts (consumables) | Requirements in terms of materials and spare parts needed for the maintenance action by considering acquisition easiness. | It will be checked:<br>* the type of materials and/or spare parts need to the work<br>* the level of market availability of those materials and/or spare parts |
| | L4 | Coordination | Complexity in the task environment: requirements for handling hazardous parts or elements, for the work permits and for the communication among different parties | It will be checked:<br>* the possibilities of dividing the work into parallel tasks<br>* the level of permits needed to perform the work |
| | L5 | Documentation | Definitions and explanations given by the maintenance plan and/or inspections related to how to perform the maintenance action. | It will be checked:<br>* the existence and completeness of maintenance plans and other descriptive documents with respect to the maintenance action to perform. |
| MAINTENANCE STAFF AND WORK CONDITIONS | S1 | Human competencies | Skills required in the maintenance staff for the kind of work to perform. | It will be checked:<br>* the level of skills needed to perform the work<br>* the degree of availability of those skills |

# APPENDIX 6

# WORKSHOP HANDOUT

*Number of pages: 8*

# WORKSHOP

Conceptual Risk Assessment Framework based on RAMS Criteria

Tânia Viana da Rocha

26 Mar 2015

# INTRODUCTION

## Background

Decision-makers often rely on data to support their decision-making processes. There is strong evidence, however, that the reliance on data with some degree of uncertainties can lead to less-effective decisions. Data collected, produced and stored in Rijkswaterstaat (RWS) is also seen as a critical aspect due to the growing use of a risk based asset management approach.

In the context of highways and waterways systems, technical and administrative data about civil structures is stored in one of the internal databases: DISK. This database aims to support maintenance-related processes by providing not just inventory data, but also the results of periodic risk oriented inspections.

However, special concerns arose about a perceived gap between the data available in DISK and the information that some decision-makers would like to have. Within the scope of a collaboration project between the University of Twente and RWS, recently we performed a set of interviews among some of the DISK data users to understand the extent of such concerns. Among other aspects, we identified a weakness on the understanding of the risk aspect adopted within a risk-based inspection and maintenance program. Such symptoms are particularly related to the risk criteria adopted in the program - RAMS - and to the way these criteria reflects the risk profiles of civil structures.

## Goals

We proposed the development of a decision-support tool for maintenance programmers. The main goal of this tool is to provide a better understanding of the risk profile of civil structures by using the RAMS indicators – and ultimately, to support the definition and characterisation of risk-based maintenance strategies within a reference period of ten years.

The goal of this workshop is to present the preliminary design of the decision-support tool and promote a space for critical discussion. Such feedback is vital not only for the validation of the tool, but also to identify potential limitations or obstacles to its implementation.

# WORKSHOP PLANNING

## Tentative agenda

The workshop is planned for the 26th of March and has an estimated duration of approximately three hours. The session will take place at the main headquarters of RWS (Utrecht) in **Gebouw Westraven, CLC: Zaal A4.1** between 14.00 and 17.00. It follows a tentative agenda for the session:

| Time | Description |
|---|---|
| 14.00 – 14.15 | Welcome. Introduction. Introduction to the RAMS-RAF model |
| 14.15 – 14.30 | Element level. Reliability risk assessment and Maintenance actions |
| 14.45 – 15.00 | Discussion |
| 15.00 – 15.30 | Element level. Maintainability, Safety and Availability risk assessment |
| 15.30 – 15.45 | Coffee Break |
| 15.45 – 16.00 | Structure level. Maintenance strategies and risk re-assessment |
| 16.15 – 16.45 | Discussion |
| 16.45 – 17.00 | Conclusions and closure |

## Participants

The list of expected attendees is presented in Appendix 1.

# RAMS-RAF MODEL

## CONCEPT

The main objective for this exercise was to develop a conceptual risk-oriented management model, which could enable a systematic determination of the present and the future, needs for maintenance, rehabilitation or eventually, replacement of civil structures or their elements. The tool is particularly relevant for maintenance programmers, since they are responsible for translating the maintenance plans provided by inspectors to a feasible implementation program to the organisation (Figure 1).

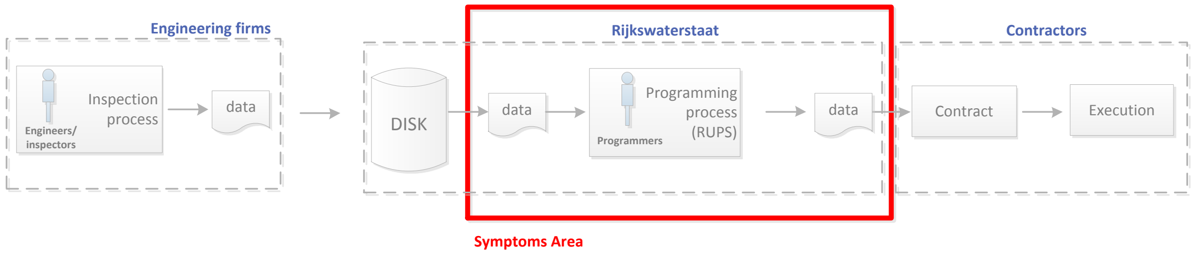



Figure 1 – Limited usefulness of the data management system to support the programming process: symptoms area in the maintenance management program

The model is fully based on the concept of real-time multi-level risk assessment, where a system of inspections work as an input to revise the risks involved in the elements of each civil structure and uses them to make line progressions over a reference period of 10 years. By better understanding such potential risks, programmers have better means to plan and prioritise maintenance actions over that period, so that risks are kept below a certain threshold.

The assessment of risk uses the RAMS aspects and their relationship as indicators, with Reliability acting as a key assessment criterion. The model can be seen as a set of blocks, each specifically designed for a specific and operative task. Each block consists of a procedure package and operational tools that can be used by the analysts responsible for the assessment. The analysts have the option to adopt deterministic judgements and/ or to make use of (semi or fully) probabilistic-based approaches. However, it is the underlying condition of the model that all the choices are justified accordingly and registered for further assessments in time.

## CONTENT

The model is grounded on performance-specific data, where the outcomes of specific blocks are needed to analyse the subsequent blocks. Therefore, it is structured in three parts: (0) structure (or system) characterisation, (1) element-level and (2) structure (or system) level.

After the characterisation of each structure in terms of structural criticality, the first part aims at identifying a maintenance action for each element based on a risk profile. The analysis starts with the assessment of Condition and Reliability levels over the reference period, which acts as a reference to select a set of alternative Maintenance Actions that can be implemented within a specific time and (if necessary) frequency, to upgrade the condition and/or reliability levels to a satisfactory or even desirable performance level. Since maintenance actions are characterised by such variables, the risk profiles of an element on maintainability, safety and availability are affected.

Understanding the risks addressed to each element is vital to strategically select a group of maintenance actions based on risk performance. However, the risk behaviour of a structure is not necessarily proportional to the risk behaviour of individual elements. Thus, the second part of the model aims at selecting a maintenance strategy for the structure also based on risks.

By defining a set of maintenance strategies, the availability risk profile is likely to be changed due to planning adjustments. Also the reliability, as a time-dependent criteria may be affected, which implies the re-evaluation of the risk profiles on the element level. The model ends with the selection of a strategy that satisfies the risks performance limits defined by RWS.

The basic parts of the model and the schematic process flow are illustrated in Figure 2. The detailed content of the model is presented in Appendix 2.

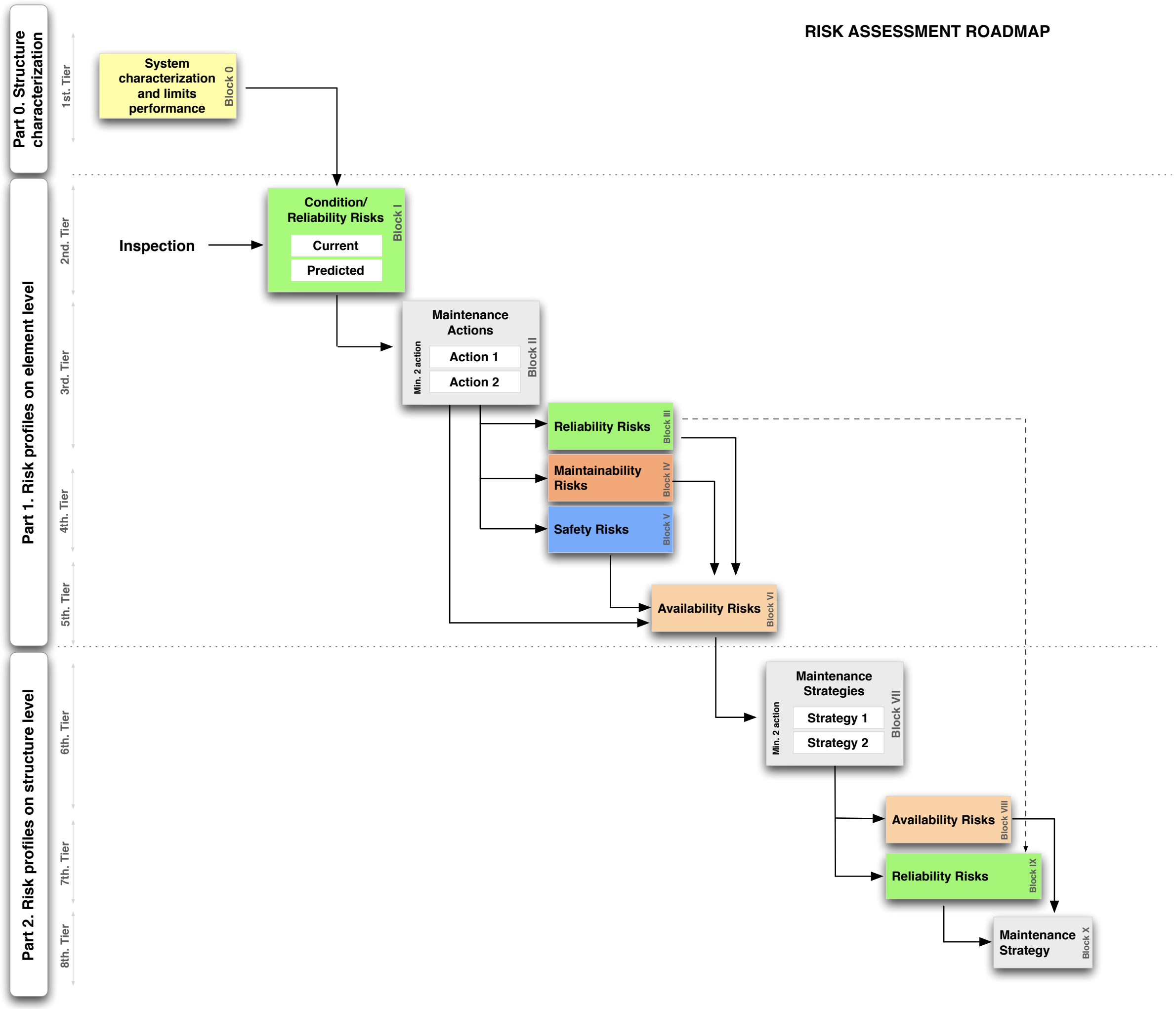



Figure 2 – Scheme of data flow over the model usage

# APPENDICES

## LIST OF ATTENDEES

| Name | Affiliation | Contact |
|---|---|---|
| Tânia Viana da Rocha | University of Twente/ RWS | t.c.vianadarocha@utwente.nl<br>+31 6 333 888 40 |
| Dr. Andreas Hartmann | University of Twente | a.hartmann@utwente.nl |
| Dr. Irina Stipanovic | University of Twente | i.stipanovic@utwente.nl |
| Jaap Bakker | RWS (Central) | jaap.bakker@rws.nl |
| Menno Nagelhout | RWS (Zeeland) | menno.nagelhout@rws.nl |
| Klaas Koning | RWS (North Holland) | klaas.koning@rws.nl |
| Bas de Ruiter | IV-Infra | p.b.deruiter@iv-infras.nl |
| Govert van Meerkerk | Nebest | govert.vanmeerkerk@nebest.nl |
| Dr. Rob Schoenmaker * | RWS/ TUDelft | r.schoenmaker@tudelft.nl |

* *Not attending, but involved in the project*

## RAMS-RAF MODEL