Asset Aggregation

Structuring condition data for decision-making

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M. Sc. Thesis

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For the past months, I have been active in the world of condition measurement and aggregation of infrastructure assets. The front page image explains the purpose of aggregation in a visual way. Aggregation combines multiple condition scores into one overall score for the asset. Sweco gave me the opportunity to investigate an alternative method of aggregating condition scores. Research in this field has helped me develop my professional skills. It has also made me discover the difficulty of creating an alternative method in fields I wasn't familiar with. Therefore, I am proud to present my thesis and hope to add value to the challenges in condition measurement and aggregation.

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Ahmet Yazan
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Figure 1 - Special thanks to Nico Broek for the NEN2767 course and taking me along an inspection of a bridge

Executive summary

One of the many challenges in infrastructure management lies in managing built assets. Managing means repairing, rehabilitating and replacing assets to ensure they are able to safely fulfill their functions. To manage infrastructure assets, detailed information about the condition of all components of the asset is required to make substantiated decisions. Assets are composed of several elements and components. Individual component condition reports represent the condition found during visual inspection. The challenge for infrastructure asset managers is how to convert data about component inspections into useful information which are aggregated to make sounds decisions on the maintenance of assets in systems. Useful data that provides information about the condition of assets in systems, which are used to support budget allocation and to prioritize maintenance, is scarce. Information may be lacking, may be incomplete, may be unorganized or may need to be deciphered before it becomes useful in decision making. Furthermore, this data would be unhelpful statistics if one does not know how to apply this information to identify problems and create solutions. At a system level, infrastructure managers need to prioritize maintenance and allocate scarce resources.

The problem of creating useful data out of large volumes of component condition inspections and reports causes decision making to be more difficult for asset owners and managers and this influences the performance of assets . Condition inspection is an activity which generates data regarding the state of an object or system. Condition inspections are based on visual inspections of assets. The inspections attempt to ascertain the presence of defects. The condition of the asset is affected by various properties of the defect. The properties are quantified along different dimensions: how serious is the defect, how extensive is the defect and what is the size of the defect? Asset owners and managers face difficulties in converting condition inspection data into useful data that enables them to compare the condition of assets or systems. An asset manager oversees many infrastructure objects. This can range from a couple of hundred to potentially thousands of objects. The aggregation of condition scores may help, but a potential problem arises when there is an abundance of condition scores. This research aims to develop a method to aggregate the component condition scores of assets to the system level. To achieve this, uniformity and objectivity need to be captured in the condition inspections and transferred to the condition aggregation phase to provide reproducibility and avoid incorrect communication.

How can we improve the current aggregation method, for aggregating component condition scores to object and system level, making it more uniform, objective and reproducible in its application?

To answer the research question this thesis has developed the OCA method, which stands for Objective Condition Aggregation.

A first step in the development of the OCA method is the identification of the problems encountered in the current NEN aggregation method. A literature review and a small but in depth case study are performed to determine current shortcomings and to identify the requirements for the OCA method. The first part of this step identifies which aggregation criteria could impact condition aggregation and the second part includes a selection process to select appropriate aggregation criteria. As a second step in the development of the OCA method, options are identified which are able to translate

criteria into numerical values. The numerical values help determine the importance of components and eventually the aggregated condition scores. As a third step the OCA method is applied to a set of 31 assets which are owned by a municipality. The engineering firm Sweco provided non-aggregated condition scores for these 31 assets.

The differences in the OCA and current NEN aggregation method have been considered. The aggregation of 31 bridges is split in three groups to compare results of aggregated condition measurements. The NEN-aggregation provides condition score results (score of 2 = good), which qualifies the asset as being in 'good' condition. The OCA is more critical and provides lower scores (score of 3 = reasonable and score of 4 = moderate), which would classify the asset condition as reasonable or moderate. As a final step, the OCA method is validated. The validity is performed by reasoning with arguments and allegations from multiple experts gathered from interviews. The information includes disadvantages of the NEN-aggregation and possible ideas to overcome them in a new developed method. It can be concluded that the current aggregation method can be improved by using condition measurements in combination with a uniform table. The OCA method shows its value by providing a step by step approach to aggregate components condition scores to system level. This approach embeds uniformity, objectivity and reproducibility. Therefore, the OCA is a better substantiated approach than the NEN-aggregation.

Finally, recommendations are given about the use of OCA. Although current inspection forms providing component condition are quite impressive, they fail to collect a crucial piece of information about the condition of the asset.

Practical recommendations are:

- Determine affected surface of components;
- Add a new heading to the inspection form called affected surface;
- Coach inspectors in how to determine the affected surface in a uniform way.

Scientific recommendations are:

- Test the design of the OCA for different assets;
- Design new uniform tables for different assets;
- Cost estimations do influence the aggregation. A different view on cost estimations will give insight in cost and aggregation accuracy;
- Design a procedure for decision making/maintenance policy with aggregated OCA condition data;
- Design a risk assessment for aggregated OCA condition data.

By doing so, an important step can be set towards standardization.

Contents

Terms & definitions

Asset	A synonym for an object or system, e.g. bridges.
Component	Components are parts element.
Condition aggregation	Multiple condition scores are translated to one condition score by a aggregation method.
Condition assessment	The condition of a component is determined by searching for defects and translating them to condition scores.
Condition determination	The component, element and object result scores are scores containing two decimals, e.g. 1,15, 1,48 etc. These result scores are converted to component, element and object condition scores through a condition determination table to decimal numbers, e.g. 1,2 etc.
Condition scores	Condition scores represent the status of a component, element, object or system.
Contribution of element/object	The costs of components or elements expressed in the total costs of the object.
Defect	A defect is a circumstance of a component where the (technical) condition is at a lower level than the (technical) condition that was intended when the component was delivered.
Effects of defects	The consequences of defects.
Element	Elements are composed of components and are parts of an object or system.
Extent defect	The surface area of the component covered by the defect.
Importance defect	The importance describes how serious the defect is. This varies from low, serious to important.
Intensity defect	The intensity describes the stadium of the defect. Has it just started, is it advanced or has it reached the end stadium.
Material cost	New price of a material.
Measure cost	Material purchase price, wages and rental equipment.
Object level	The object level describes the condition of the object and is composed of elements and components.
OCA	Objective Condition Aggregation Method.
System level	The system level describes the condition of the system and is composed of objects, elements and components.
Uniform table	This table includes components, defects and measures to help aggregate in a uniform way.

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1. Introduction

1.1 Condition aggregation

Condition inspection is a method in civil engineering to assess and express the condition of components in a singular score (NEN, 2017). The condition inspection assesses the condition of various asset components and the resulting scores are often combined into one overall score. This process is called condition aggregation. The overall condition score, the aggregated score, tells something about the condition of the state of an asset. In the Netherlands, NEN2767 is used as a method by infrastructure asset owners to assess the condition of components (NEN, 2017). The norm which standardizes and more or less objectivizes the condition inspection procedure is quite new (NEN2767). The NEN2767 aggregation (Appendix VI.) could be improved on the following points: aggregation leading to low condition scores (1-2), the influence of different aggregation criteria besides material cost and the impact of defects in aggregation. However, a uniform objective method for aggregating the component condition scores in a reproducible way is currently lacking. Reproducibility will assist in the realization of a more uniform and clear understanding of infrastructure condition assessment.

1.2 Relevance of condition assessment and condition aggregation

Why and for who is condition aggregation relevant? Condition aggregation is relevant for asset owners, asset managers and service providers. The aggregated condition data is important for monitoring (development of asset condition in years), benchmarking (comparison of assets) and budget allocation (how to spend budget) (Straub, 2009). The asset owner determines on a strategic level (long term) the goals and frameworks to be used for infrastructure maintenance. The asset manager translates the objectives on a tactical level (medium term) into functional requirements, sets up the asset systems, determines what new assets need to be added, what maintenance is required and provides frameworks for these objectives. The service provider acts on an operational level (short term) and takes care of the practical design, construction and maintenance. They are responsible for managing different types of assets, e.g. bridges, tunnels, railways, electricity networks, locks, flood defenses, etc., etc..

One of the key requirements for asset management by an asset manager is to be aware of the condition of the assets. Therefore, aggregating condition scores provides valuable data to make strategic decisions in the management of assets (Mohseni, Setunge, Zhang, & Wakefield, 2013). *Figure 2* shows the wide range of support for an asset manager's decision making.

What is the condition of my system x?

↓

Inspection of components and aggregation

↓

Organize results (decomposition, condition scores, defects etc. of inspection results and aggregation)

↓

1. Visualize the condition of a system (combination of multiple assets).
2. Substantiate yearly maintenance plans and maintenance programming.

3. Substantiate maintenance budgets.
4. Support technical management and policy.
5. Use in maintenance contracts.
6. Facilitate communication about desired condition.

Figure 2 - Aggregating component condition scores to system level to support a wide range of an asset manager's decision making (own design)

1.3 Literature review of condition scores aggregation

This part provides a summarized literature review about infrastructure condition assessment and aggregation in several research papers divided in different categories such as rating models (the calculation method), aggregation criteria (the criteria that are included the weighting) and visual inspection. In-depth literature analysis and summaries are found in Appendix I and II.

Very few researchers have researched condition assessment and aggregation. However, those that do mention that there is no set standard for aggregating condition scores (Zayed & Semaan, 2008; Bolar, Tesfamariam, & Sadiq, 2013). Researchers have created different methods to aggregate condition scores. A uniform standard to aggregate condition data and gain comparable and objective results and to have common understanding of the aggregated condition scores is still lacking. The current Dutch standard for condition aggregation in the built environment weighs the importance of components in the same group based on historical data from Dutch Qualitative Housing Registration 2000 (KWR 2000), e.g. element is main support construction and counts for four, component is support and counts for two (Straub, 2006; Straub, 2009). The different categories in the papers will be treated next.

Rating models to determine overall condition scores influence the reliability of the aggregation. According to Omar, Nehdi, & Zayed (2017) one rating model for aggregation is by expert judgement. In interviews, common defects were compared on a 9-points scale. An overall condition score was determined by combining different inspection technique results. Bolar, Tesfamariam, & Sadiq, 2013 use a hierarchical tree to classify elements of an object into four categories: primary, secondary, tertiary and life safety-critical. Each element is rated for having a probability of CS-1 to CS-5 on HER-scale (e.g. element 1 has 95% probability CS-1 and 5% CS-3 (Bolar, Tesfamariam, & Sadiq, 2013)). The formule of Yager can be used to compute the overall condition index for various categories. However, this method is complex and involves a lot of uncertainty in the sense that many variables for each element have to be determined. The infrastructure condition assessment model (Zayed & Semaan, 2008) is nearly similar to the research by Omar et al. (2017). The difference is the method of data collection via questionnaires. The data is tested by statistical and sensitivity analyses. A paper by Chouinard et al. (1996) uses information from a historical database to rate each component and prioritize the weight based on the importance of function. Some rating models do use aggregation criteria.

Aggregation criteria are crucial in setting up an aggregation model based on component level to provide reliable (overall) condition scores. Aggregation is reached if defects are detected and translated to weights (Zayed & Gkountis, 2015). Several criteria defined by Inkoom et al. (2017 & 2018) are availability importance, element material cost, long-term cost and vulnerability to hazard risks. In this approach the determination of weights is primarily focused on cost estimates and their vulnerability for strong winds and/or floods. A condition assessment model by Gkountis et al. (2015) proposes a process on how to determine common defect weights. This done by a pairwise comparison scale of comparing the importance of elements by a 5-point qualitative scale including minimum, most probable and maximum value for the probability of a certain condition. According to

Mohseni (2013) the criticality of components needs to be categorised. Criteria presented to determine weights are probability of failure, condition, deterioration curve and relative consequence of failure. The research by Abbott et al. (2007) is comparable with the research of Inkoom et al. (2017), because aggregation criteria such as maintenance, rehabilitation and material cost are in both researches relevant for determining (overall) condition scores. The type of aggregation criteria can have a huge impact on how visual inspection is performed and on the results, because a change in criteria will provide a different set of weights.

Visual inspection provides condition data to assess the condition of assets. Visual inspections are important aspects for proposing a rating model with reliable aggregation criteria to assess civil infrastructure. To make this successful it is key to collect objective information from visual inspection to help in decision making (Quirk, Matos, Murphy, & Pakrashi, 2018) for ageing assets (Anzola & Vila, 2016). With this information the condition is assessed and can be predicted (Mehairjan, Djairam, Zhuang, & Smit, 2014) and helps guarantee certain availability, reliability, service and safety levels of the asset (Rafiq, Chryssanthopoulos, & Sathananthan, 2015).

1.4. Problem statement

1.4.1 Introduction NEN2767

Many public organizations like the Department of Waterways and Public Works, regional governments (provinces), municipalities, water boards and asset owners in the Netherlands use a standard visual inspection method (NEN2767) to assess the condition of their infrastructure assets and determine potential defects. Components are inspected for importance, intensity and extent of the defects, see Appendix VI for details. (NEN, 2017). In Figure 3 an example decomposition is shown. The decomposition is based on the type of asset and is made by the asset owner or asset manager.

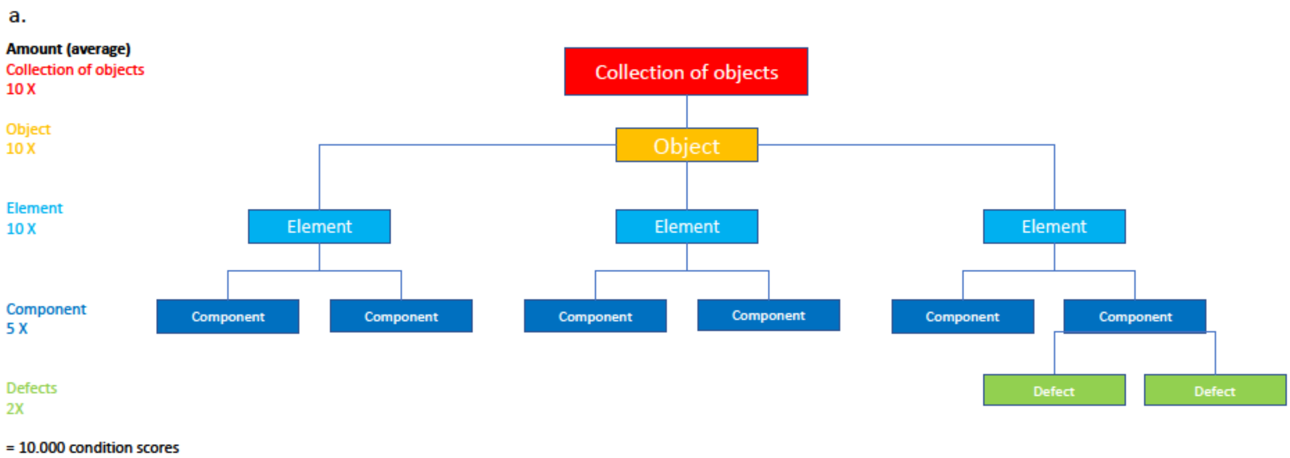

Figure 3 - A general decomposition

In Figure 3 a decomposition example is shown. The collection of objects (top level) is a system composed of different objects (high level). The object is a single asset composed of different elements (medium level). The elements are parts of the object. The components (low level) are parts of the elements and each component may have a defect. In short, the object is an asset which is further decomposed in smaller parts for inspection on the lowest level (elements and components).

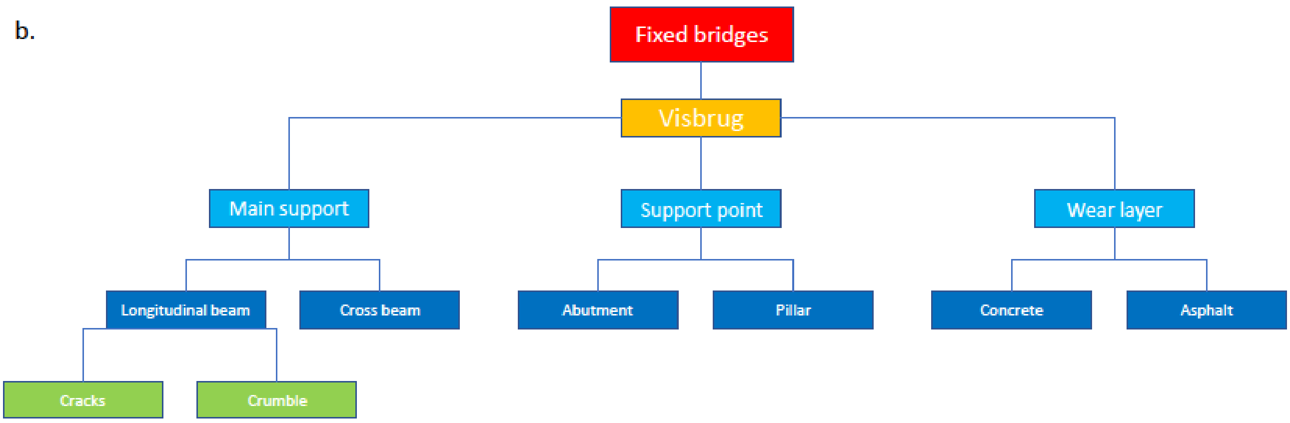

Figure 4 - A fictive example

In Figure 4 a fictive example is introduced. The collection of objects is called fixed bridges. The object refers to a fixed bridge (Visbrug). Fixed bridges, and the Visbrug among them, are composed of elements such as main support, support point and wear layer. The elements are decomposed into components. Visual inspection determines the condition of the components and locates defects. Each component can have defects and each defect will receive a condition score on a 6-point scale.

Now, a hypothetical example will be given to better understand the issue with condition scores. Suppose an asset owner manages a collection of 10 different objects (e.g. fixed bridges, movable bridges, tunnels, divers, locks etc.). Each collection of objects is further decomposed in different objects from each collection (e.g.in the fixed bridges, we can identify visbrug, boterbrug, etc.). Suppose each infrastructure object can subsequently be further decomposed in 10 elements such as main support, support point and wear layer. And these elements can be decomposed in 5 different components. For each of these there is a condition score. The resulting condition scores available to the asset owner thus will amount to ten thousand scores. Imagine then that one of these components has 2 defects. The asset manager will have 10 thousand condition scores on the defects and is faced with the challenge to compose meaningful object and system based decision making information from this huge amount of data.

An asset manager oversees many infrastructure objects. This can range from a couple hundred to potentially thousands of objects. A potential problem arises when there is an abundance of condition scores. As mentioned before, the volume of condition scores will make it challenging how to use them. Decision making becomes difficult, e.g. budget allocation, maintenance and repairs. Therefore, it is desirable to aggregate the component condition scores to reduce the amount of data.

1.4.2 Problem 1: Low condition scores (1-2) of components

The Dutch infrastructure sector uses a standardized condition assessment method for the built environment (NEN, 2017). As an example, a civil object and its condition is assessed via visual inspections. The inspector inspects the components of the object visually by looking for any defects which can be detected. If a defect is found it will be scored on a 6-point scale (1 excellent - 6 very bad) based on importance, intensity and the extent. Since the condition scores are given on a component level, many scores are generated. This creates uncertainty about how to best use the condition scores and makes it difficult to determine the condition of assets on a system level. Most of these condition scores (Figure 5), or around 70 – 80% fall in the category condition score 1 or 2, since the affected surface system is small <2% and between 2 – 10 %. The affected surface weighs heavily in determining the condition score (see *Figure 5*). The remaining 20 – 30% falls in the category condition score 3, 4, 5 or 6. See Appendix VI. for details.
In many cases crucial defects (e.g. structural cracks) have condition score 1 or 2, due to a small surface. This is a serious issue, because these defects can cause collapse or other serious accidents which may result in consequential damage. A defect like structural cracks receiving a low condition score such as 1 (excellent) or 2 (good) would not be an appropriate reflection of the potential risks.

Conditionscore NEN2767						
Defect	**Intensity**	< 2% incidental	2 - 10 % local	10 - 30 % regularly	30 - 70 % considerably	> 70 % general
low	start	1	1	1	1	2
	advanced	1	1	1	2	3
	end	1	1	2	3	4
serious	start	1	1	1	2	3
	advanced	1	1	2	3	4
	end	1	2	3	4	5
important	start	1	1	2	3	4
	advanced	1	2	3	4	5
	end	2	3	4	5	6

Figure 5 - Determination of condition score of defects by importance (low, serious, important), intensity (start, advanced, end) and extent (between <2% and > 70%) *(NEN, 2017)*

1.4.3 Problem 2: Material cost as criterion

Important steps in the aggregation are the choice of criteria and the translation to numerical weights. The current NEN-aggregation uses material cost as criterion (NEN, 2017). The 'new' price is calculated by the unit price and the surface of a component. However, material costs is one way to aggregate, but it is certainly not the 'best' way. This is because the material costs of a large component may be very high, because of the large surface of the component. Also, a component with no defect has no influence on the functionality of the object. Meanwhile, a small component may have a defect and low costs, because of the smaller surface. But it does have direct influence on the functionality of the object. However in the current NEN aggregation, a large surface component with higher costs weighs heavier than small surface components with lower costs. This provides unbalanced results, because assets with large surface components in a good condition score higher on aggregated condition scores.

1.4.4 Problem 3: Defect

Defects are fundamental in condition assessment and aggregation. In the current NEN-aggregation, consequences of defects are not considered in the aggregation. The identified defects can potentially have major consequences. An innocent looking crack can lead to collapse of a bridge, but as mentioned consequences of defects don't play a role in the current NEN-aggregation.

1.5 Goal

The goal of this research is:

'To develop a method to aggregate the component condition scores of infrastructure assets to the system level, making it more uniform, objective and reproducible in its application by considering the limitations of the current aggregation method.

Uniformity and objectivity are key goals in the current condition inspection method NEN2767 (NEN, 2017). It is a must to continue these aspects in aggregation to gain reproducibility. Aggregating the component condition scores to the system level will reduce the number of scores and provide a clearer condition state and add value in decision-making, e.g. how to spend budgeted funds, when to perform maintenance and how to prioritize the order of repairs.

1.6 Research gap

Limited research is performed on the aggregation of condition scores to help in decision making in asset management. The literature does not provide an easily applicable and uniform aggregation method for various infrastructure assets by using data from condition inspection. The literature focuses on developing rating models, identifying criteria, managing and predicting condition data to gain aggregated condition scores. Disadvantages of aggregation methods mentioned in literature mention: Selecting different criteria for each case (Bolar, Tesfamariam, & Sadiq, 2013; Mohseni, Setunge, Zhang, & Wakefield, 2013), the abundance of condition scores (Straub, 2009) and their subjectivity (Mohseni, Setunge, Zhang, & Wakefield, 2013; Bolar, Tesfamariam, & Sadiq, 2013), the unavailability of data in practice (Inkoom & Sobanjo, 2018) and unreliable data (Inkoom, Sobanjo, Thompson, Kerr, & Twumasi-Boakye, 2017; Zayed & Gkountis, 2015), the uncertainty of aggregation and the cost in time (Omar, Nehdi, & Zayed, 2017), complex steps (Omar, Nehdi, & Zayed, 2017; Zayed & Gkountis, 2015; Bolar, Tesfamariam, & Sadiq, 2013), accuracy of results (developing methodology is main idea (Omar, Nehdi, & Zayed, 2017; Bolar, Tesfamariam, & Sadiq, 2013)) and use of different methods for each object or system (Bolar, Tesfamariam, & Sadiq, 2013). The researches indicate that aggregating component condition scores to the system level is lacking. Therefore, a research gap within aggregation to the system level has been found. This gap is aimed to be resolved within the scope of this research.

1.7 Research question

1.7.1 Introduction

The problem statement and objectives make it clear that a method for aggregation is required. This method should solve current issues: A more objective and uniform method (low condition scores (1-2) of components (chapter 1.4.2)), material cost as a criterion (chapter 1.4.3) and defect (chapter 1.4.4). This chapter introduces the research question.

1.7.2 Main-question

This research focusses on the development of a method to aggregate component condition scores to the system level so that 'experts' may reach the same aggregation assessment (uniformity). The following research question is defined:

> How can we improve the current aggregation method, for aggregating component condition scores to object and system level, making it more uniform, objective and reproducible in its application?

1.7.3 Sub-questions

The sub-questions identify three aspects which need to be addressed in the design of the new method.

1. **Which criteria should be taken into account when aggregating from the component to the system level?**

This question seeks to identify key criteria influencing the aggregation process. A literature review and two brainstorming sessions were held to determine key criteria. Interviews were held to seek additional criteria, gain support and compare views.

2. **Having identified the relevant criteria, how should these criteria be weighted and aggregated to object and system level?**

This part of the research is focused on the issue of how to translate the aggregation criteria that were identified (SRQ 1) into component weights (numerical values). The current NEN-aggregation uses the surface system and the material price to determine component weights. The new OCA method includes new aggregation criteria and influences of defects. The research question is split in two parts, 2.a is object level and 2.b is system level. In chapter 4, the aggregation to object level is executed. In chapter 5, the aggregation to system level is executed.

3. **How does the proposed aggregation method perform in relation to the NEN-aggregation method?**

Finally, the new proposed design is validated by logical reasoning about the following questions: 1. How does the current NEN-aggregation work? 2. What are the disadvantages of the current NEN-aggregation method? 3. How can we overcome the disadvantages? 4. How did we incorporate these suggestions into a new method? 5. What are the benefits of the Objective Condition Aggregation (OCA) method?

1.8 Scope

To ensure a practicable project, choices were made with regard to the design of the research. This research is:

I. Intended for public authorities, engineering firms and contractors.
II. Intended to develop an aggregation method that facilitates objectivity to help in decision-making, e.g. repairs, budget allocation and benchmarking etc.
III. Intended to aggregate from component to system level.
IV. Limited to determine aggregated condition score of fixed bridges (availability of data) in different systems, but also applicable to other assets such as tunnels, railways, electricity networks, locks, flood defences, etc..
V. Aggregation is applicable to system level if 'system' includes comparable assets, e.g. 20 same type of bridges, 10 tunnels etc. Not applicable for complex and unique objects.
VI. Dependent on limited availability and accessibility of collected data.
VII. Limited to determine consequences of defects. The probability of consequences of effects is not considered.
VIII. Dependent on proposing repairs, replacements etc. for aggregation reasons. These propositions may be used in practice, but they should be used in combination with other methods supporting the choice of propositions.
IX. Dependent on cost calculated or estimated as an average. These can differ in practice.

1.9 Research outline

Figure 6 covers the outline of the research and the research question, sub-questions and research objective. The introduction in chapter 1 describes the relevance of the research, literature review and provides the problem statement. This makes it possible to define a goal and research questions. In chapter 2, the methodology is developed and the design of the OCA framework is shown.

To gather data for the OCA framework, a literature analysis, brainstorm sessions and interviews are held in chapter 3 to determine aggregation criteria. The aggregation steps of the OCA method and NEN method to object level are shown in chapter 4. The aggregation steps of the OCA method and NEN method to system level are shown in chapter 5. In chapter 6, the OCA is evaluated to prove its validity. In chapter 7, the discussion is presented. In chapter 8, the conclusions are drawn and recommendations are given regarding the OCA and research proposals.

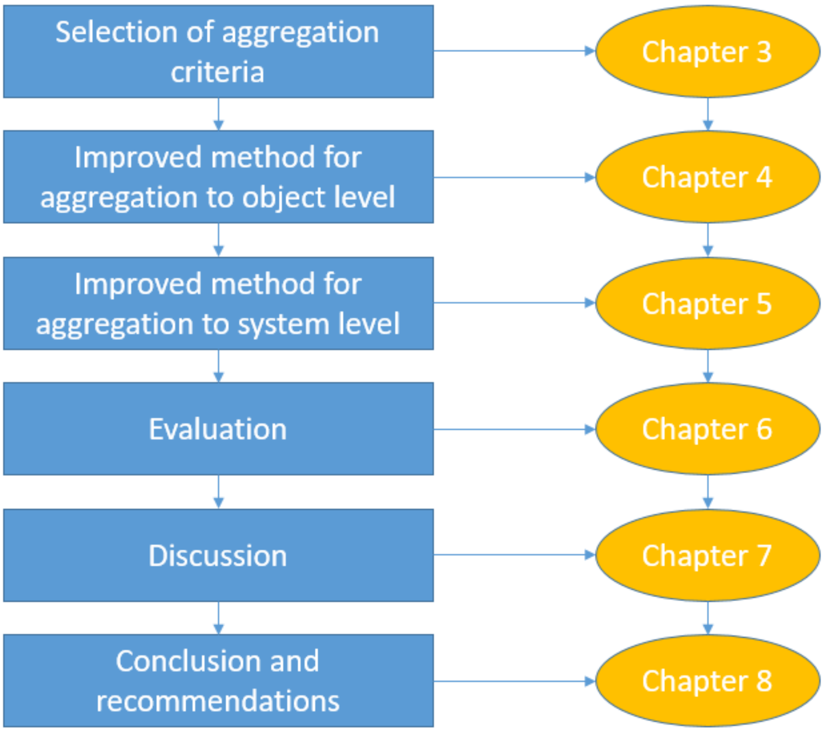

Figure 6 - Research outline

2. Methodology

2.1 Introduction

This chapter will explain the entire framework/design of the research: the choice of paradigm, methods and tools or techniques to explore research questions and to create new knowledge (Williamson, 2018).

The need for and methods of objective condition ranking

There is a need for a condition ranking method which enables the 'objective' management of assets (Wierzbicki, 2010). Most approaches (decision analysis, multi criteria theory) focus solely on (inter)subjective ranking, because decisions are based on personal experience, memory, thoughts, thinking paradigms and the psychological states (Yu, 1990). Objectivity is desirable, but the true state and perceived state are usually not the same. People use their perceived state to make decisions while it influences other people. According to Wierzbicki (2010), absolute objectivity is known not to be attainable. Therefore, we must transfer knowledge that is as objective as possible to future generations, to help face uncertainty. The concept of objective ranking is not absolutely objective, but as objective as possible and dependent on a given set of data (Wierzbicki, 2010). Since absolute objectivity can't be reached, a goal is set to achieve rankings that are as objective as possible, e.g. generate objective aggregation data (on the condition of assets) by using a standardized condition inspection method (NEN2767).

2.2 Overall research design

The overall research design for the development of the new aggregation method can be seen in *Figure 7*. The research is executed in five steps:

1. Start with understanding, reporting and deciding what problem to solve. This is done in chapter 1.
2. Formulate a suggestion about how to solve the problem.
3. The next step is the development of a prototype of a new method.
4. The new method will generate results. The method must be evaluated to check if the requirements are met and to confirm their validity.
5. Finally, some decisions and conclusions about the method will be drawn.

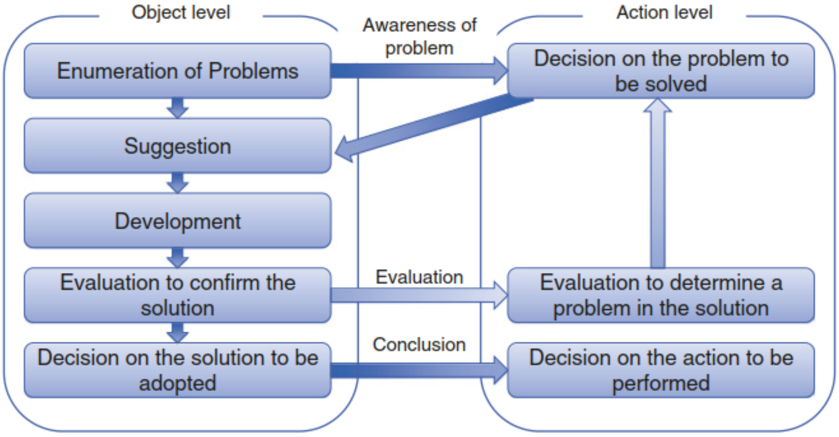

Figure 7 - Design science for conducting research (Dresch, Lacerda, & Antunes Jr., 2015)

The research design for the new OCA aggregation method starts with the selection and explanation of a case study and the problem. Next, the case study is described and analyzed to understand and suggest a solution for the problem. To learn how the current method works and finding a way to produce weights of the components. Measures to solve or mitigate the effects will be determined and finally expressed in costs. Based on the available data two assets with sufficient defects are selected for a case study to test how the criteria can be applied in aggregation (Appendix IV. and VII.). One municipal wooden bridge and one concrete bridge belonging to a Province. The criteria are applied to assets with more than one defect. In this way, it is possible to solve or mitigate the effects and express the measures in costs.

2.3 Methods

This section will provide an overview of the various methods and how they could add value to the research.

2.3.1 Interviews

Semi-structured interviews are performed to gather information and determine the pros and cons of aggregation criteria. According to Longhurst (2003), advantages of semi-structured interviews are: accurate understanding and gathering of information, deeper understanding of research questions, flexibility of two-way communication, and it is a conversation rather than asking questions and getting answers. The potential downsides are: each interview is unique and comparing results is difficult, inaccuracies and response bias.

Added value

The interviews are used to gather information about the current NEN-aggregation, find new aggregation criteria and gain their opinions regarding proposed questions from their experiences in the field.

2.3.2 Multi-criteria analysis (MCA)

Multi Criteria Analysis is used to identify the most preferred option, rank options by detailed appraisal or to separate acceptable and unacceptable options (Dodgson, 2009).

The multi-criteria analysis (MCA) is a tool to help in decision-making processes within complex environments/projects and is non-monetary. This means that criteria aren't directly related to monetary value or policy, as not all effects can be quantified and expressed in financial terms. Therefore, MCA is suited for qualitative, (long term) effects of problems in the environment, health, safety and the vulnerability of involved groups. The MCA doesn't steer into a specific direction. Its focus lies in analyzing various situations and the interests of stakeholders. Different situations and interests provide the possibility of comparing and weighing all effects in different ways. The weighing shows the interest of each stakeholder. Each stakeholder will have a ranking list for their benefit.

Pros and Cons

The power of the MCA method is the comparison of uncorrelated information and structuring relevant information for decision making (Dodgson, 2009). The desirability of alternatives follows from the allocation of weights to different effects: 'How important is an effect within a group of effects compared to completely different effects. Often, assigning weights explicitly involves political considerations. Therefore, it is desired to involve stakeholders in this process to gain insight in considerations, interests and arguments. The purpose and focus of an MCA are process and decision support. Cons of the MCA are the lack of guidelines and standard methods for determining criteria and weights. Therefore, the application of MCA is not univocal.

Added value
The MCA is an excellent tool for decision-making in complex projects. In this research, it has shown its value by finding a relationship between criteria and the importance of defects. Consequences of defects related to criteria are tested in Appendix VII. All types of criteria are considered even if expressing them in monetary terms was difficult.

2.3.3 Societal cost-benefit analysis (SCBA)

Cost-benefit analysis should not solely be concerned with monetary inputs or outputs. The main goal is the overall welfare of stakeholders and society. However, the monetary value is used as a common unit to express heterogeneous items in social cost and benefits to appraise (de Rus, 2010).

The social cost-benefit analysis (SCBA) is a tool to help in investment decisions. It helps decide whether an investment adds value by considering societal costs and benefits. In other words, efficient assessment to identify how to use scare resources to gain the optimal benefits (Hakkert & Wesemann, 2005). With cost-benefit analysis, the consequences of the alternatives are valued monetary. The consequences are afterwards displayed in a cost-benefit balance. The SCBA is a monetary value. This means that criteria are directly related to financial values or monetary policy. All direct and indirect effects (costs and benefits) should be expressed in monetary terms (de Rus, 2010). External effects (environment and health) are difficult to quantify and monetize, but inclusion of an estimated value for analysis is necessary (Hakkert & Wesemann, 2005) . Therefore, they should be monetarized wherever possible. The result of a SCBA is to check the "profitability" of alternatives to see if the investment adds value in benefits in excess of all potential costs. Finally, the alternatives are compared based on net present value (NPV), benefit cost ratio (BCR) and internal return (IR).

Pros and Cons
The SCBA methods strength is to express effects in monetary terms. The monetary value for external effects are determined by decision processes or empirical research. The external effects can be determined by various methods. The downside of these methods are very different outcomes. In practice it is difficult to express external effects as a monetary value. Since external effects such as environment and health are long term effects, a monetary value may be difficult to estimate accurately. Therefore, in the SCBA view it is desired to limit the timespan. However doing so makes external effects often hardly visible and they play a minor role in decision making. The criteria which can't be valued or estimated in monetary terms are not included in a cost-benefit analysis of ranking alternatives. As a complement it is useful to determine the ranking with multi-criteria analysis solely on non-monetary criteria (Hakkert & Wesemann, 2005).

Added value
The SCBA is strong in expressing effects in monetary values but it is more difficult to express the external effect of defects in monetary terms. The SCBA gave the idea to develop measures to solve defects and their effects in various criteria by developing uniform tables. In this way, it became easier to translate measures in monetary values, because a fixed uniform table makes deviations unnecessary.

2.3.4 Evaluation

This research is based on design science and according to Tremblay et al. (2010), research should not only focus on developing new methods. Research also must demonstrate if real problems can be solved. Hevner et al. (2004) suggest five ways to evaluate design science research. The five ways are: (1) observational (2) analytical (3) experimental (4) testing, and (5) descriptive. Explanations are given in *Table 1*.

Table 1 - Methods and techniques for the evaluation of methods (artifacts, Hevner, 2004)

Form of evaluation	Proposed methods and techniques
Observational	Case study elements: study the existing or created artifact in depth in the business environment Field study: monitor the use of the artifact in multiple projects
Analytical	Static analysis: examine the structure of the artifact for static qualities Architecture Analysis: study the fit of the artifact in the technical architecture of the complete technical system Optimization: demonstrate the optimal properties inherent to the artifact or demonstrate the limits of the optimization in the artifact behavior Dynamic analysis: study the artifact during use to evaluate its dynamic qualities (e.g., performance)
Experimental	Controlled experiment: study the artifact in a controlled environment to determine its qualities (e.g., usability) Simulation: execute the artifact with artificial data
Testing	Functional test (*black box*): implement the artifact interfaces to discover potential failures and identify defects Structural test (*white box*): perform coverage tests of some metrics for implementing the artifact (e.g., execution paths)
Descriptive	Informed argument: use the information of knowledge bases (e.g., relevant research) to construct a convincing argument about the utility of the artifact Scenarios: construct detailed scenarios for the artifact to demonstrate its utility

Selection of evaluation technique

The evaluation technique must show if the requirements which are stated in chapter 7.1 are met and describe why the OCA method is better than the NEN-aggregation for fulfilling its purpose. The five techniques will be discussed for their applicability:

- Observational: case study elements are not applicable, because it has already been used to derive requirements and understand how the NEN-aggregation works. Field study is not suited, because aggregation cannot be tested by this type of study.
- Analytical: The relationship between actual and benchmark data is reviewed to try and identify if variations exist. Since the OCA method is new, a comparison by actual and benchmark data is not yet possible.
- Experimental & Testing: No additional results will be gained by conducting experiments or performing a test. The results of the OCA method are based on multiple assets being tested and experimented with.
- Descriptive: Since there is no absolute truth (a benchmark), it is difficult to validate the NEN-aggregation and OCA based on cases and results. The two methods provide different results.

Only on the basis of reasoning can we indicate if and why the OCA method is in most instances better, e.g. added aspects that the NEN-aggregation does not consider.

The **descriptive informed argument** is chosen as a suitable evaluation technique based on the discussion about their applicability. Descriptive evaluation helps collect data to determine if a phenomenon can or cannot be quantifiable and seeks to demonstrate the applicability of the developed method (Hevner, 2004). According to Bruseberg and Mcdonagh-Philp (2002) the descriptive evaluation is supported by a focus group to assist in the development of ideas and opinions of methods. Evaluation is performed through reasoning, because there is no absolute truth (a benchmark). Only on the basis of reasoning can we indicate why the OCA method is in most instances better, e.g. added aspects that the NEN-aggregation does not consider. The information gathered from knowledge bases (focus group) will be used to construct convincing arguments (Hevner, 2004). The design in *Table 2* includes the following questions which are answered by participants in the focus group.

Table 2 - Evaluation design

Questions
1. How does the current NEN-aggregation work?
2. What are the disadvantages of the current NEN-aggregation method?
3. How can we overcome the disadvantages?
4. How did we incorporate these suggestions into a new method?
5. What are the benefits of the Objective Condition Aggregation (OCA) method?

3. Selection of aggregation criteria

3.1 Introduction

This chapter is the first step of developing the method and will determine the criteria that contribute to aggregation. Brainstorm sessions and literature are reviewed in parallel. Individual brainstorm sessions will be held to stimulate the generation of ideas for criteria (Coon, 2006). After a list of criteria is determined, the literature will be reviewed to support similar or nearly similar criteria. Followed by semi-structured interviews (Barriball & While, 2006) with experts to gain their views and opinions on criteria. This chapter will answer the following sub-question:

Which criteria should be taken into account when aggregating from component to the system level?

Determining the criteria is crucial. The combination of brainstorm sessions, literature and semi-structured interviews will provide an overview of qualified criteria.

3.2 Brainstorm sessions for criteria

The brainstorm sessions are held with Ben Visser. Sessions are held to determine aggregation criteria on the component level. First, two sessions are held to determine criteria. Later, two additional sessions are conducted to check if all possible criteria are found. Further, definitions are listed from literature in *Table 3*.

Table 3 - Criteria definition

Criteria	Definition
Material cost	Cost in € for a new component.
Defect cost	Total cost in € for fixing or solving defects attached to components.
Safety	Safety issues for users and workers caused by defects.
Functionality	Functionality of an asset affected by defects.
Risk	Risks with technical triggers with economical (company image) and societal impact.
Environment	Accessibility, quality living system, nuisance. Damaged done to the system caused by defects.
Availability	How available the asset is based on planned and unplanned downtime.
Reliability	Failure or malfunction affecting the reliability of the asset.
Deterioration	How fast the condition is deteriorating (condition prediction).

Aesthetics	Graffiti, vegetation and pollution affecting asset aesthetics.

3.3 Verifying criteria with literature

The brainstorm sessions provide an overview of criteria to aggregate condition scores within different literature studies (*Table 3*). To substantiate criteria, literature is analyzed in Appendix I and II. This will help compare criteria from brainstorm sessions and literature to aggregate condition scores. In this way, it can be substantiated that these criteria are commonly used and are suitable options for aggregating condition scores. Ten criteria are described in literature. See *Table 4* with literature referencing.

1. **Material cost:** Optimized cost models are important for effective resource allocation. Different costs like failure cost, repair cost, material cost and long-term cost are included in these models (Inkoom & Sobanjo, 2018). Material costs were successfully used as an alternative way to determine weights (Inkoom S. , Sobanjo, Thompson, Kerr, & Twumasi-Boakye, 2017). Therefore, material cost can help in determining weights and budget spending (Straub, 2009).
2. **Defect cost:** Defect cost considers repair cost. Inkoom et al. (2017) focused on calculating weights by considering the repair cost of a component. The importance of repair costs for condition assessment is also stated and considered by Grigg (2006).
3. **Safety:** The consequences of defects for the safety of users and workers is of crucial importance. Mohseni et al. (2013) divides the criticality of components into three parts: appearance, consequence of failure, health and safety criteria.
4. **Functionality:** The weights for components are determined by the fitness for purpose (function fulfilment). This process involves the goal that needs to be reached (Zayed & Gkountis, 2015) by defining important functions of assets (Zayed & Semaan, 2008). According to Mohseni et al. (2013) it is crucial to consider the fitness for purpose to satisfy the expected function and quality of assets.
5. **Risk:** According to Inkoom et al. (2017) assets are vulnerable to natural and manmade hazard risk. Typical hazards are strong winds, flooding, fire and collision. Other risks depend on technical triggers (asset related) and non-technical triggers (stakeholder related) (Mehairjan, Djairam, Zhuang, & Smit, 2014).
6. **Environment:** No application is present in literature.
7. **Availability:** The performance of an asset depends on different criteria, one of which is availability. The availability of an asset is vital to guarantee certain service and safety levels (Rafiq, Chryssanthopoulos, & Sathananthan, 2015). The availability of elements are assessed by indicators such as downtime, repair times (Inkoom & Sobanjo, 2018) and even predictive condition data (Mehairjan et al., 2014; Abbott et al., 2007). Risk based management focusses on preventive repairs or replacements before an incident happens (Bolar, Tesfamariam, & Sadiq, 2013). Complex assets are subject to downtime and require large amount of funds for maintenance (Zayed & Gkountis, 2015; Chouinard et al., 1996) and rehabilitation (Zayed & Semaan, 2008).
8. **Reliability:** Reliability of elements are assessed in failure rates, repair times (Inkoom & Sobanjo, 2018) and malfunctions (Zayed & Gkountis, 2015). According to Mohseni et al. (2013); Bolar et al. (2013) asset reliability is influenced by criticality, asset type, relative age, rate of deterioration and economic value of the outcomes to the business. Other criteria influencing the level of reliability are functional life, aging, repair cost and lacking

proper rehabilitation planning (Zayed & Semaan, 2008; Grigg, 2006; Chouinard et al., 1996).

9. **Deterioration:** Lots of uncertainty is involved in determining the effect of deterioration on critical components (Inkoom & Sobanjo, 2018). Long term performance issues are inevitably caused (Omar, Nehdi, & Zayed, 2017) and these are difficult to predict (Quirk, Matos, Murphy, & Pakrashi, 2018). To deal with asset deterioration, it's crucial to analyze real condition and collect data to determine interventions for ageing assets (Anzola & Vila, 2016). Important aspects in deteriorating systems are asset specific condition data, timely condition data, predictive condition data (Rafiq et al., 2015; Zayed & Gkountis, 2015; Mehairjan et al.,2014; Bolar et al., 2013; Abbott et al., 2007) and rate of deterioration (Mohseni, Setunge, Zhang, & Wakefield, 2013).
10. **Aesthetics:** No application is present in literature.

Table 4 - Literature framework

	Criteria	*Sylvester Inkoom & John Sobanjo (2018)*	*Lucy Quirk et al. (2018)*	*T. Omar, M. L. Nehdi & T. Zayed (2017)*	*Sylvester Inkoom et al. (2017)*	*Maria ANZOLA & Carlos VILA (2016)*	*M. Imran Rafiq et al. (2015)*	*Iason Gkountis & Tarek Zayed (2015)*	*R.P.Y. Mehairjan et al. (2014)*	*Hessam Mohseni et al. (2013)*	*Aman Bolar et al. (2013)*	*Ad Straub (2009)*	*Nabil Semaan & Tarek Zayed (2008)*	*Abbott et al. (2007)*	*Neil S. Grigg (2006)*	*Ad Straub (2006)*	*L. E. Chouinard et al. (1996)*
1	Material cost	X			X							X			X	X	
2	Defect cost				X										X		
3	Safety									X							
4	Functionality							X		X			X				
5	Risk				X				X								
6	Environment																
7	Availability	X					X	X	X		X		X	X	X		X
8	Reliability	X					X			X	X		X		X		X
9	Deterioration	X	X	X		X	X	X	X	X	X			X			
10	Aesthetics																

In chapter 3.3 a description is given about the possible aggregation criteria mentioned in literature. In *Table 4*, an overview about the criteria commonly used and/or suitable for aggregating condition scores in literature is provided. This table shows how many times an aggregation criteria is mentioned in literature.

3.4 Semi-structured interviews with experts

Four experts with NEN2767 inspection and aggregation experience were interviewed. From these four interviewees, information was gathered about the general background of NEN2767, their working experience within projects and how they experienced the workability of the NEN-aggregation method. Questions about this topic formed the foundation for asking about criteria that can improve and develop the aggregation method. During the interviews, interviewees were asked to score the added value (good, average or bad) of criteria and their strength in further developing the aggregation method. In *Table 5* the results of the interviews are presented. In Appendix III all interview questions and answers are available.

Table 5 - Results interviews

	1	2	3	4	5	6	7	8	9	10
	Material cost	Defect cost	Safety	Functionality	Risk	Environment	Availability	Reliability	Deterioration	Aesthetics
Project Manager	Good	Good	Average	Average	Average	Bad	Bad	Average	Bad	Average
Director/Senior Advisor 1	Good	Bad	Good	Good	Average	Good	Average	Average	Bad	Good
Senior Advisor 2	Good	Good	Average	Bad	Bad	Average	Good	Good	Bad	Average
Senior Advisor 3	Good	Good	Good	Good	Good	Good	Good	Average	Bad	Bad
Result	**Good (4X)**	**Good (3X), Bad (1X)**	**Good (2X), Average (2X)**	**Good (2X), Average (1X), Bad (1X)**	**Good (1X), Average (2X), Bad (1X)**	**Good (2X), Average (1X), Bad (1X)**	**Good (2X), Average (1X), Bad (1X)**	**Good (1X), Average (3X)**	**Bad (4X)**	**Good (1X), Average (2X), Bad (1X)**

It can be seen that material and defect costs score best. These were followed by safety, functionality, environment and availability. Reliability and aesthetics both scored a single good. The worst is deterioration. Before the interviews it was decided to neglect criteria which received more than two bad.

3.5 Selection of criteria for aggregation

This chapter gave all the necessary information to conclude the following sub-question:

'Which criteria should be taken into account when aggregating from the component to the system level?'

The current inspection method and the views of experts provided input for the requirements. The selection of criteria is based on:

1. Which criteria are considered during inspection;
2. The possibility of translating the effects of defects to criteria;
3. The opinion of experts and their reasoning about the added value of criteria.

Table 6 - Selecting aggregation criteria and definitions (green criteria we incorporate, red criteria we exclude)

	Criteria	Explanation	Definition
1	Material cost	Material cost shows the importance of components expressed in €, more expensive translates in more important.	Cost in € for new component.
2	Defect cost	Measures taken to solve defects are considered as the defect cost.	Total cost in € for fixing and/or solving defect attached to component.
3	Safety	Safety of assets affected by components is important and should be considered as priority.	Safety issues for users and workers.
4	Functionality	Already considered during inspection (1).	Functionality of an asset affected by defects.
5	Risk	Risk assessment is the next step after determining the condition of asset (3).	Risks with technical triggers with economical (company image) and societal impact.
6	Environment	The consequences of decisions on environment within projects is becoming more important. Leaving future generations with an equal or better environment is essential.	Accessibility, quality living system and nuisance. 'Damage' to the system.
7	Availability	The availability is considered for an asset and not for a component (2).	How available the asset is based on planned and unplanned component downtime.
8	Reliability	The reliability is considered for an asset and not for a component (2).	Failure/malfunction of the components affecting the reliability of the object/system.
9	Deterioration	Deterioration curve is included in methodology of NEN2767 and the deteriorating of condition is determined by regularly inspecting 1-3 years (1,2,3).	The rate which the condition of components is deteriorating (condition prediction)
10	Aesthetics	The aesthetics of assets are representative for the system and should be maintained at agreeable levels (3).	Graffiti, vegetation and pollution or anything else affecting object aesthetics. Further effects/reflections on company image/reputation.

4. Improved method for aggregation to object level

4.1 Introduction

In this chapter, the traditional NEN method and new OCA method is described for aggregation to object level. The stepwise procedure, scoring methods and examples will be explained. Finally, a comparison between the traditional NEN method and OCA method at object level will be given and the following sub-question will be answered:

Having identified the relevant criteria, how should these criteria be weighted and aggregated to object level?

The numerical weights of components will be gained by scoring each component with a defect according to the five criteria determined in chapter 3. If a component has no defect, it will get the condition score 1.

4.2 Description of traditional NEN method for aggregation to object level

4.2.1 Stepwise procedure

This part describes the steps to aggregate condition scores from component to object level following the traditional NEN-method. The steps (1-4) are preliminary to the aggregation and are presented to provide a clear image of the total aggregation process. **More details on the aggregation method are found in Appendix VI.**

1. Scope: define the scope of the object or system. This will set the base for the next step, because a clear scope will help to understand the boundaries of the object.
2. Decomposition: a decomposition of the object is necessary to gain an overview of all elements and components. This step sets the base for inspection. The inspector has an overview of the components to inspect.
3. Inspection: based on the decomposition of the object, the inspector will visually inspect and search for component defects. The component defects will be analyzed by three aspects: seriousness, size and intensity.
4. Condition scores on component level: based on the inspection results each component will receive a condition score from 1 to 6.

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5. Material cost as aggregation criteria: the next step is to determine the material cost of every component expressed in euro's.
6. Elements result score: the aggregation from component to element level is based on the component decomposition, component condition scores, component material cost and dedicated correction factors provided by the NEN-method (NEN 2627).
7. Elements condition score: the elements result score is converted by condition determination.
8. Object result score: the aggregation from element to object level is based on the element decomposition, element condition scores, element material cost and the correction factors provided by the NEN-method.
9. Object condition score: the object result score is converted by condition determination.

10. The final result is the aggregated condition score of the object from 1 to 6 where 1 is an excellent overall condition and 6 a very bad and unacceptable overall condition.

1	2	3	4	5	6

4.2.2 Examples

The wooden bridge was built in 1976 and provides passage for mixed traffic (*Figure 36*). The bridge is the link between a residential system and a school. The bridge is used by pedestrians, bicycles, cars and small trucks.

The aggregation which considers material cost has provided a aggregated **condition score 4** for the wooden bridge on a scale 1-6. The contribution of each component is provided on a scale from 0 to 1 and the total contribution of all components amounts to 1. The elements are composed of several different components. Therefore, the contribution of one element is more than another element, because the contribution of an element is based on the components. The contribution of each component, element and condition score of the object are seen in *Table 7*.

Table 7 - Aggregation only material cost for the case study wooden bridge (NEN-method)

Object	Condition score	Elements	Contribution of element (0-1)	Components	Contribution of component (0-1)
Wooden Bridge	4	Anti-vandalism provision	0,05	Fence	0,05
		Main supporting structure	0,58	Longitudinal beam	0,28
				Pole	0,13
				Drive deck	0,17
		Handrail construction	0,07	Handrail	0,07
		Wear layer	0,11	Wear layer (general)	0,11
		Support	0,18	Support (general)	0,18

The concrete bridge over the Roer in the N293 in Roerdalen (St. Odiliënberg) consists of three parts which can be seen in *Figure 37*: a concrete arch bridge, rebuilt in 1948 (originally built in 1908), and on both sides of the concrete arch bridge free bicycle bridges, built in 1976.

The aggregation which considers material cost has provided an aggregated **condition score 1** for the concrete bridge on a scale of 1-6. The contribution of each component is provided on a scale from 0 to 1 and the total contribution of all components amounts to 1. The elements are composed of several different components. Therefore, the contribution of one element is more than another element, because the contribution of an element is based on the components. The contribution of each component, element and condition score of the object are seen in *Table 8*.

Table 8 - Aggregation only material cost for the case study concrete bridge (NEN-method)

Object	Condition score	Elements	Contribution of element (0-1)	Components	Contribution of component (0-1)
Concrete Bridge	1	Guide construction	0,03	Guiderail	0,03
		Main supporting structure	0,82	Main supporting structure (general)	0,00
				Beam	0,22
				Arch	0,46
				Drive deck	0,15
		Rainwater drainage	0,00	Drain	0,00
				Pond	0,00
		Handrail construction	0,12	Handrail	0,12
		Bearing	0,02	Bearing (general)	0,02
		Support	0,24	Pillar	0,00
				Abutment	0,23
				Support beam	0,00
				Foundation block	0,00
		Slope	0,01	Slope (general)	0,007
				Revetment	0,003
		Expansion joint	0,07	Sealing strip	0,00
				Expansion joint (general)	0,07

4.3 Description of new OCA method for aggregation to object level

4.3.1 Stepwise procedure

This part will describe the steps of the new OCA method to aggregate condition scores from component to object level. The OCA method builds on the traditional NEN-method. It uses the same inspection approach and the same correction/conversion factors. However, improvements are proposed in the weighting of the components in the aggregation. Whereas the traditional NEN uses component replacement costs (material costs), the OCA method proposes to use the cost of mitigating the risks of detected defects in components.

The OCA methods is described by the following steps. Again, the steps (1-4) are preliminary to the actual aggregation and are meant to provide a clear image of the total aggregation process. **More details of the OCA method are found in Appendix VI.**

1. Scope: define the scope of the object or system. This will set the base for the next step, because a clear scope will help to understand the assignment and the boundaries of the object.
2. Decomposition: a decomposition of the object is necessary to gain an overview of all elements and components. This step sets the base for inspection. The inspector has an overview of the components to inspect.
3. Inspection: based on the decomposition of the object, the inspector will visually inspect and search for component defects. The component defects will be analyzed by three aspects: seriousness, size and intensity.
4. Condition scores on component level: based on the inspection results each component will receive a condition score from 1 to 6.
5. Uniform table: build a uniform table with unit costs of measures to solve and/or mitigate possible defects in components. This step is done once and results in a generalized measure and cost table to be used in following applications of the OCA method.
6. Select the appropriate measure and unit cost for all identified component defects from step 3: for each defect a measure and cost can be found in the uniform table.
7. For each component determine the defects' surface areas: the defects cover a certain percentage of the surface area of components. This area has to be determined in m2 or m3.
8. Costs: for each component and its defects calculate the total cost of the selected risk mitigation measures. This is done for each measure by multiplying the unit measure cost and the surface area.
9. Elements result score: the aggregation from component to element level is based on the component decomposition, component condition scores, total component measure costs and the correction factors conform the traditional NEN-method.
10. Elements condition score: the elements result score is converted by condition determination.
11. Object result score: the aggregation from element to object level is based on the element decomposition, element condition scores, total element measure costs and correction factors conform NEN2767.
12. Object condition score: the object result score is converted by condition determination.
13. The final result is the aggregated condition score of the object from 1 to 6.

1	2	3	4	5	6

4.3.2 Examples

The aggregation which considers all five criteria (material, defect, safety, environment and aesthetics) has provided a aggregated **condition score 5** for the wooden bridge. The contribution of each component is provided on a scale from 0 to 1 and the total contribution of all components amounts to 1. The elements are composed of several different components. Therefore, the contribution of one element is more than another element, because the contribution of an element depends on the number of components. The contribution of each component, element and condition score of the object are seen in *Table 9*.

Table 9 - Aggregation all three criteria for OCA method

Object	Condition score	Elements	Contribution of element (0-1)	Components	Contribution of component (0-1)
Wooden Bridge	5	Anti-vandalism provision	0,02	Fence	0,02
		Main supporting structure	0,77	Longitudinal beam	0,37
				Pole	0,34
				Drive deck	0,07
		Handrail construction	0,09	Handrail	0,09
		Wear layer	0,05	Wear layer (general)	0,05
		Support	0,07	Support (general)	0,07

The aggregation which considers material cost has provided an aggregated **condition score 2** for the concrete bridge. The contribution of each component is provided on a scale from 0 to 1 and the total contribution of all components amounts to 1. The elements are composed of several different components. Therefore, the contribution of one element is more than another element, because the contribution of an element is based on the components. The contribution of each component, element and condition score of the object are seen in *Table 10*.

Table 10 - Aggregation all three criteria for OCA method

Object	Condition score	Elements	Contribution of element (0-1)	Components	Contribution of component (0-1)
Concrete Bridge	2	Guide construction	0,02	Guiderail	0,02
		Main supporting structure	0,88	Main supporting structure (general)	0,23
				Beam	0,14
				Arch	0,38
				Drive deck	0,14
			0,00	Drain	0,00

		Rainwater drainage		Pond	0,00
		Handrail construction	0,08	Handrail	0,08
		Bearing	0,01	Bearing (general)	0,01
		Support	0,16	Pillar	0,00
				Abutment	0,15
				Support beam	0,17
				Foundation block	0,00
		Slope	0,01	Slope (general)	0,005
				Revetment	0,005
		Expansion joint	0,05	Sealing strip	0,00
				Expansion joint (general)	0,05

4.4 Comparison between traditional NEN method and OCA method at object level

The aggregation of condition scores from component to object level are in *Table 11*. The difference between the scores is caused by additionally weighing defects according to safety, environment and aesthetics. Therefore, all criteria weigh heavier in this case. The weight depends on the condition scores and cost.

Table 11 - Results of aggregation

	Wooden bridge	Concrete bridge	Criteria
NEN2767	4	1	Material cost
OCA	5	2	Safety, environment & aesthetics

As mentioned in chapter 1, uniformity is desired. A uniform table is derived from the case study for material cost and measure cost. The tables are in Appendix VIII.

A crucial part of aggregation is the translation of criteria to weights. The current NEN-aggregation uses material cost as criterion. Material cost of a large component maybe very high because of the large surface system. Also, a component with no defect has no influence on the functionality of the object. Meanwhile, a small component may have a defect and little cost, because of the smaller surface system. But it does have direct influence on the functionality of the object. A large surface component with higher cost weighs in most cases heavier than small surface components with lower cost. This provides an unbalanced condition of scores, because large surface components provide disproportional 'good' and 'healthier' aggregated condition scores.

Therefore, in the OCA criteria are translated into weights by providing fixed measures for defects in a uniform table. This process is as follows: find the component and defect, use the uniform table to select a measure and cost, determine the affected surface system and calculate the cost and finally determine weights by condition score and cost. The idea behind the measures is that they solve or mitigate any potential safety, environment and aesthetic issue. In this way, the criteria will always produce reproducible results.

5. Improved method for aggregation to system level

5.1 Introduction

In this chapter, the traditional NEN method and new OCA method is described for aggregation to system level. The stepwise procedure, scoring methods and examples will be explained. Finally, a comparison between the traditional NEN method and OCA method at system level will be given and the following sub-question will be answered:

Having identified the relevant criteria, how should these criteria be weighted and aggregated to system level?

The numerical weights of components will be gained by scoring each component with a defect according to the five criteria determined in chapter 3. If a component has no defect, it will get the condition score 1.

5.2 Description of traditional NEN method for aggregation to system level

5.2.1 Stepwise procedure

This part describes the steps to aggregate condition scores from component to system level following the traditional NEN-method. The steps (1-4) are preliminary to the aggregation and are presented to provide a clear image of the total aggregation process. **More details on the aggregation method are found in Appendix VI.**

1. Scope: define the scope of the object or system. This will set the base for the next step, because a clear scope will help to understand the boundaries of the object.
2. Decomposition: a decomposition of the object is necessary to gain an overview of all elements and components. This step sets the base for inspection. The inspector has an overview of the components to inspect.
3. Inspection: based on the decomposition of the object, the inspector will visually inspect and search for component defects. The component defects will be analyzed by three aspects: seriousness, size and intensity.
4. Condition scores on component level: based on the inspection results each component will receive a condition score from 1 to 6.

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5. Material cost as aggregation criteria: the next step is to determine the material cost of every component expressed in euro's.
6. Elements result score: the aggregation from component to element level is based on the component decomposition, component condition scores, component material cost and dedicated correction factors provided by the NEN-method (NEN 2627).
7. Elements condition score: the elements result score is converted by condition determination.
8. Object result score: the aggregation from element to object level is based on the element decomposition, element condition scores, element material cost and the correction factors provided by the NEN-method.
9. Object condition score: the object result score is converted by condition determination.

10. System result score: the aggregation from object to system level is based on the object decomposition, object condition scores, object material cost and correction factors.
11. System condition score: the system result score is converted by condition determination.
12. The final result is the aggregated condition score of the system from 1 to 6.

1	2	3	4	5	6

5.3 Description of new OCA method for aggregation to system level

5.3.1 Stepwise procedure

This part will describe the steps of the new OCA method to aggregate condition scores from component to system level. The OCA method builds on the traditional NEN-method. It uses the same inspection approach and the same correction/conversion factors. However, improvements are proposed in the weighting of the components in the aggregation. Whereas the traditional NEN uses component replacement costs (material costs), the OCA method proposes to use the cost (Appendix VII.) of mitigating the risks of detected defects in components.

The OCA methods is described by the following steps. Again, the steps (1-4) are preliminary to the actual aggregation and are meant to provide a clear image of the total aggregation process. **More details of the OCA method are found in Appendix VI.**

1. Scope: define the scope of the object or system. This will set the base for the next step, because a clear scope will help to understand the assignment and the boundaries of the object.
2. Decomposition: a decomposition of the object is necessary to gain an overview of all elements and components. This step sets the base for inspection. The inspector has an overview of the components to inspect.
3. Inspection: based on the decomposition of the object, the inspector will visually inspect and search for component defects. The component defects will be analyzed by three aspects: seriousness, size and intensity.
4. Condition scores on component level: based on the inspection results each component will receive a condition score from 1 to 6.
5. Uniform table: build a uniform table with unit costs of measures to solve and/or mitigate possible defects in components. This step is done once and results in a generalized measure and cost table to be used in following applications of the OCA method.
6. Select the appropriate measure and unit cost for all identified component defects from step 3: for each defect a measure and cost can be found in the uniform table.
7. For each component determine the defects' surface areas: the defects cover a certain percentage of the surface area of components. This area has to be determined in m2 or m3.
8. Costs: for each component and its defects calculate the total cost of the selected risk mitigation measures. This is done for each measure by multiplying the unit measure cost and the surface area.
9. Elements result score: the aggregation from component to element level is based on the component decomposition, component condition scores, total component measure costs and the correction factors conform the traditional NEN-method.
10. Elements condition score: the elements result score is converted by condition determination.

11. Object result score: the aggregation from element to object level is based on the element decomposition, element condition scores, total element measure costs and correction factors conform NEN2767.
12. Object condition score: the object result score is converted by condition determination.
13. System result score: the aggregation from object to system level is based on the object decomposition, object condition scores, total object measure costs and correction factors.
14. System condition score: the system result score is converted by condition determination.
15. The final result is the aggregated condition score of the system from 1 to 6.

1	2	3	4	5	6

5.3.2 Examples

The aggregation which considers all three criteria (safety, environment and aesthetics) has provided a aggregated **condition score 3** for the system including 31 bridges. The contribution of each object is provided on a scale from 0 to 1 and the total contribution of all objects amounts to 1. The objects are composed of several different elements and components. Therefore, the contribution of one object is more than another object, because the contribution of an object is based on the elements and components. The contribution of each object and condition score of the system are seen in *Table 12*.

Table 12 - Aggregation all three criteria of OCA method

System	Condition score	Objects	Contribution of object (0-1)
System including 31 bridges	3	1	0,065
		2	0,015
		3	0,011
		4	0,012
		5	0,003
		6	0,005
		7	0,021
		8	0,019
		9	0,035
		10	0,054
		11	0,050
		12	0,005
		13	0,011
		14	0,014
		15	0,033
		16	0,026
		17	0,114
		18	0,062
		19	0,135
		20	0,005
		21	0,007
		22	0,010
		23	0,007

		24	0,007
		25	0,026
		26	0,003
		27	0,157
		28	0,031
		29	0,001
		30	0,001
		31	0,057

5.4 Comparison between traditional NEN method and OCA method at system level

In *Table 13* the results of the different aggregations of 31 bridges are seen. These results are split into 3 systems to compare the differences in condition scores between both methods to answer the following sub-question:

'How does the proposed aggregation method perform in relation to the NEN-aggregation method?'

Table 13 - Aggregation of wood bridges (20) and concrete bridges (11)

	Total system	Wood system	Concrete system
NEN2767	2	2	2
OCA	3	3	4

According to the results in *Table 13* the NEN-aggregation provides good condition score results in all systems. The OCA is more critical and provides reasonable and moderate condition scores.

The difference in scores is related to which aggregation method is used. NEN-aggregation considers all components and aggregates based on the new cost of each component. OCA only considers components with defects and aggregates based on measures to solve or mitigate defects. The similarities and differences between NEN2767 and OCA are given in *Table 14* and described in detail in this part.

Table 14 - Similarities and differences of NEN and OCA

NEN2767	OCA
Similarities	
Objectivity	
Inspection results	
Decomposition	
Condition determination	
Differences	

Semi simple, the material cost have to be estimated every single time	Very simple, the measure cost are fixed and can be used every single time
No uniform table for aggregation	Uniform table for aggregation
Different results, because costs need to be determined every single time	Reproducible results through uniform tables
Material cost (costs of the new purchase price of a component)	Measure cost (costs of a measure to solve component defects)
All components are included	Only components with defects are included
Effects of defects are not considered	Effects of defects are solved or mitigated
Serious defects of a small size give low condition scores (1-2)	Low condition scores are tackled by solving these defects with measures
Risks are not solved or mitigated	Risks are solved or mitigated

Similarities between NEN and OCA aggregation

- Objectivity: objectivity provides a greater chance of reliable results, because there are no special interests or individual bias involved. Objective methods are needed to determine results without considering the possible outcome, interests or motives of any party. Reliable results are reached if the conclusions that are drawn on the basis of the results do not depend on the opinion or interests of any party. Thus, the new aggregation methods aim to act as objective as possible.
- Inspection results: the NEN2767 inspection provides data regarding component condition in an objective and uniform way. Based on seriousness, size and intensity components with defects receive a condition score varying from 1 to 6. This data is very important, as it will be the base for aggregation.
- Decomposition: the decomposition in the OCA is identical to the NEN2767.
- Condition determination: the condition determination tables and numbers in the OCA is identical to the NEN2767.

Differences between NEN and OCA aggregation

1. Simplicity: a great reason why simplicity often works is that a simple solution is usually understood by everyone. This avoids communication problems, confusion and differing interpretation of results. Therefore, the aggregation method needs to be easy in use and understanding.
2. Uniformity**:** Each asset manager/owner has their own way of determining material cost, e.g. asset manager 1 uses material costs in the north of Holland and asset manager 2 uses costs in the south of Holland. The effect is a large variance in results. Asset owners and managers benefit from standardization. Uniformity, where possible, makes processes clearer and more efficient. Confusion will be avoided if the same methods, symbols and formulations are used. Uniformity makes the process of aggregation easier to understand and avoids confusion in communication.
3. Reproducibility: similar results are obtained with research conducted under comparable conditions. Uniformity and objectivity strengthen the reproducibility of results. Data is collected and processed in the same way. Therefore, results are reliable and give the same results under comparable circumstances. Reproducibility in aggregation will ease communication, avoid confusion and facilitate the interpretation of results.

4. Material and measure cost: the material cost of a large component maybe very high, because of the size. This component has no influence on the functionality of the object, because zero defects are found. In the NEN2767 aggregation this component with condition score 1 is considered. Therefore, better aggregated scores are gained, because the contribution of the large component compared to other components is significantly higher.
   The measure cost are specifically designed for components with defects. Each component and its possible defects are standardized in a table. This table eases the aggregation by providing fixed measures and costs. In this way, all defects, measures and costs can be easily selected from this table.
5. Component consideration: the NEN2767 considers all components in the aggregation even if they have no effect on the functionality, safety etc. of the asset. Therefore, the NEN2767 aggregation provides good condition scores in many cases.
   The OCA considers only components with defects, because these have an effect on the functionality, safety etc. of the asset. Therefore, the OCA aggregation provides a true reflection of the defects.
6. Defects consideration: the effects of defects are not considered in the NEN2767 aggregation. The problems caused by defects can have serious consequences. An innocent looking crack can lead to collapse of a bridge.
   The standardized table for OCA aggregation is designed by considering the effects of defects on criteria such as safety, environment etc. The measures in the table are designed to mitigate and/or solve the effects of these defects.
7. Serious defects and low condition scores (1): most condition scores (70/80 %) from inspection are in category 1 or 2. The reason is the affected surface area of the component. The surface area of a component is one of the main criteria and weighs heavy in determining the condition scores. If the affected surface area of the component is small in comparison with the total surface area it leads to low condition scores (1). The remaining 20/30 % of the condition scores are in category 3,4,5 or 6. It is a serious issue when crucial defects (structural cracks) are given condition score 1 or 2 due to small defect area, because the severity of the defects are blurred. The OCA tackles tries to tackles this problem by mitigating and/or solving the defects by measures. In this way, the severity of the defects isn't faded in the aggregation.
8. Risks: the defects introduce risks for the assets, e.g. structural cracks causing structural instability of the asset. These risks are not considered in the NEN2767.
   The OCA does indirectly treat such risks by mitigating and/or solving the defects causing risks.

The OCA tried to solve the above mentioned aspects by using a standard table (Appendix VII). The influence of material cost is removed, because only components with defects are considered. The consequences of these defects are considered in aggregation and are mitigated/solved via various measures. The risks derived from condition scores are clearer, because the OCA treats such risks by mitigating and/or solving the defects causing risks.

6. Evaluation

6.1 Introduction

This chapter discusses the validity of the OCA method. The designed method has to satisfy the requirements and successfully fulfil its purpose. According to Pries-Heje and Baskerville (2008) the developed method must show that it satisfies the required conditions to achieve the desired and expected objectives. In short, a method must completely accomplish its function. Chakrabarti (2010) acknowledges that validity is a key factor to facilitate and support the practical application of research. Mentzer and Flint (1997) also acknowledge the importance of validity to ensure that research conclusions are safely asserted.

6.2 Validation

The reliability of this research is analyzed by reasoning to determine if the OCA method satisfies the requirements and successfully fulfils its purpose. However, proving the reliability of qualitative research is often difficult. Therefore, multiple experts are consulted in interviews to gather information including disadvantages of the NEN-aggregation and possible ideas to overcome them in a new developed method. The following question will be answered:

How is the proposed OCA method design valid?

As mentioned before in chapter 4 and 5, the current NEN-aggregation requires the decomposition of an asset (inspection data), the condition score of components (inspection data) and the replacement cost of components (calculate from own sources). After collecting the information, NEN-aggregation is performed via multiple steps described in 4.2 and 5.2 (see Appendix VII. for example).

The experts mentioned the disadvantages of the NEN-aggregation. These are: all components are considered, with and without defect. Components without influence (no defect) on the functionality of the object should not be included (Director/Senior Advisor 1). The results are often inaccurate, because components with totally different functions are compared by material cost. The main supporting structure is compared with a handrail, these components contribute differently to the functionality of the object and therefore it is inaccurate to compare them only by material cost (Interview Project manager). The results are limited, because material cost is not the only criterion that influences the aggregation. In practice, aggregation based on material cost does not work (Senior Advisor 3). The calculation of material cost requires a lot of time. The surface system and unit price for each individual component has to be determined. Therefore, most asset owners do not want material cost as an aggregation criteria (Senior Advisor 2). Also, risks can become invisible and may not be identified when aggregated condition scores indicate the overall condition of the asset is good (Interview Project manager).

The disadvantages of the NEN-aggregation are tackled in the OCA method. This is done as follows: good components with a large surface system can 'distort' the aggregated condition, resulting in a relatively high condition score (good). As a result, some risks resulting from bad conditions can 'disappear'. Therefore, only components with defects are considered in the OCA method, thus negating the 'good conditions'. The result of this is that relatively high condition scores are eliminated. In addition to material cost several other criteria are added in the OCA method. The criteria are combined in a standard table for defects and costs and is created from inspection data.

The standard table includes measures to overcome defects by fixed measures and unit costs. This table facilitates uniformity and eases the estimation of the costs of solving, eliminating or mitigating defects. The result is reproducibility for future aggregation analysis.

The disadvantages of the NEN-aggregation are tackled in the OCA method and have shown that the OCA has the following benefits over the NEN method:

- Uniformity: use of a standard table that includes the cost estimation of measures to solve defects. In this way, the aggregation cannot deviate because a fixed solution is ready. This makes the aggregation process more transparent and more efficient. Confusion will be avoided, because there is only one way to perform the aggregation. Uniformity makes the process of aggregation more understandable and avoids confusion in communication.
- Objectivity because components with different functions are aggregated based one more than one criteria. This provides a greater chance of objective results, because the outcome is based on the cost to solve or mitigate the defect for each criteria. The outcome no longer depends solely on replacement cost. More objective results are reached if the conclusions drawn on the basis of the results do not depend on a single criterion.
- Reproducibility is gained by proposing measures for the defects. Uniformity and objectivity strengthen the reproducibility of results. All necessary data is collected through inspection and processed in the same way. By combining this data with a standard table to eliminate defects the process of aggregation is standardized. This standardization provides reproducibility, eases communication, avoids confusion and clarifies the interpretation of results.
- Minimizes costs, time and the amount of work. Only the surface system and the measure cost of defects are considered.
- Risks resulting from bad conditions of components in an asset become more visible in the overall condition score. The aggregated condition score is a direct reflection of the components with defects only and therefore it stays visible, because now bad conditions of components cannot be aggregated to good condition scores. In this way, only condition scores that represent risks are shown.
- Simplicity. The OCA method is a simple process that could be understood by everyone. The aggregation is performed in simplified steps. It is also easy to automatize the execution of the OCA method by creating a program.

The validation shows that the proposed OCA method design is valid, because the developed Objective Condition Aggregation (OCA) is a new method to determine to condition of assets in an system by incorporating criteria like safety, environment, material cost, defect cost and aesthetics. The method considers defects and the costs of eliminating each defect when aggregating condition scores from the component to the system level. In this way, criteria are monetarized and turned into numerical values to serve as measurements for the aggregation. This research is intended to develop a method to identify the condition of systems in a uniform, objective, reproducible and simple to understand way. This research serves as the basis for further studies to perfect the aggregation of components into values of quantifiable risks. This will help users make sounds decisions can benefit efficiencies and product optimal returns on capital projects and public investments. The specified values in this method should not be taken as the only permanent measurements of values. A simple method is developed based on data with reasonable values to explain this process in general but practical terms.

7. Discussion

In this chapter, the discussion is presented. The requirements, background and applicability is explained for the chosen assets. Further, the limitations of the research are discussed.

7.1 Requirement OCA method

The development of a new method starts with setting the requirements. The requirements for the new aggregation method are based on different sources which can be seen in *Figure 8*. The requirements are derived from case study, literature and users. In chapter 3, the literature has been consulted. In Appendix VIII, the case study has given great consideration about applying current NEN-aggregation including possible solutions. Finally, user requirements are derived during execution of the case study (Appendix VIII) and interviews (Appendix III) to ease the application process. The goal of user requirements is to make the new aggregation method easy to use and understand.

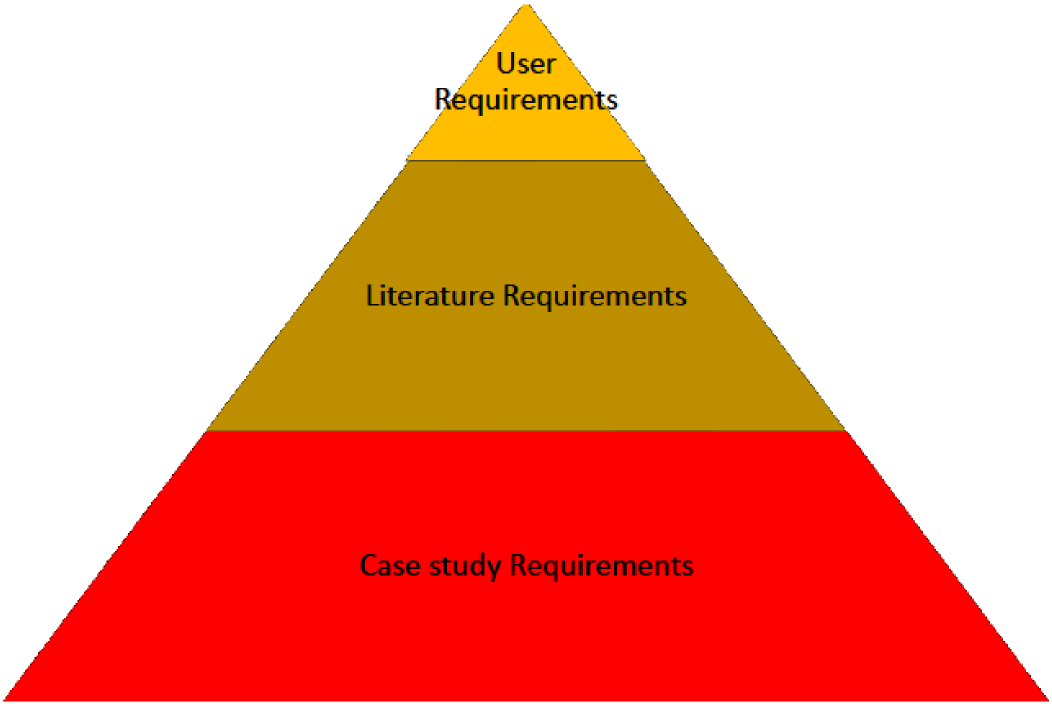

Figure 8 - Requirements triangle

7.2 Limitations OCA method

The research took place in the context of an engineering firm for the assets of governmental organizations. The OCA method is developed to aggregate the condition scores of these assets. Besides the OCA there are different ways of aggregating. Based on the requirements of the aggregation other or better ways of aggregating may exist. The OCA is developed based on research, and is a form of aggregation that fits the wishes and requirements.

The research identifies three aspects which play a role in developing the OCA method, the criteria, uniform table and cost.

- **Criteria:** In total 10 criteria were identified, 5 of them were selected to contribute in the aggregation, and 5 of them omitted. These findings were based on certain literature and interviews with experts. As such, different criteria might have been identified and chosen if different literature and experts had been chosen. As shown in the validation chapter, the method is valid and should not differ if applied to other assets. Yet, the contribution of these criteria cannot be guaranteed for all assets.

- **Uniform table:** The uniform table was developed for this data set of assets and has showed how aggregation could be done differently in a uniform way. However, there are far more measures to add, because each asset has different defects. Since this research focused on aggregating fixed bridges, other type of assets and their uniform table measures are not investigated to check the possibilities.

- **Cost:** Finally, the cost contains uncertainties, because these are calculations derived from an engineering firm. These uncertainties can potentially overstate or understate cost estimates. The main goal of this research was to estimate an average, but realistic cost. Therefore, it is not the focus of this research to have costs with a degree of complete certainty. In the present model cost uncertainties are related to average cost. As a result, these costs can differ for assets, but for standardization and reproducible purposes an average is chosen.

In addition to the discussed aspect another important aspect is data. Some data may also not yet be available, accurate or proven. Therefore, gaps may be filled by cost documents, databases and estimates by a cost expert.

8. Conclusion and recommendations

This chapter contains the conclusions, discussion and recommendations of this research.

8.1 Conclusions

This part provides the conclusions of the research that was conducted. The research aimed to develop a method to aggregate the component condition scores of infrastructure assets to the system level, making it more uniform, objective and reproducible in its application by considering current problems. The following research questions were identified and subsequently answered.

- *''How can we improve the current aggregation method, for aggregating component condition scores to object and system level, making it more uniform, objective and reproducible in its application?''*
  The aggregation method can be improved by aggregating to the system level by the OCA method making it more uniform, objective and reproducible as stated in chapter 5.3.

  The validation shows that the proposed OCA method design is valid, because the developed Objective Condition Aggregation (OCA) is a new method to determine to condition of assets in an system by incorporating criteria like safety, environment, material cost, defect cost and aesthetics. The method considers defects and the costs of eliminating each defect when aggregating condition scores from the component to the system level. In this way, criteria are monetarized and turned into numerical values to serve as measurements for the aggregation. This research is intended to develop a method to identify the condition of systems in a uniform, objective, reproducible and simple to understand way. This research serves as the basis for further studies to perfect the aggregation of components into values of quantifiable risks. This will help users make sounds decisions can benefit efficiencies and product optimal returns on capital projects and public investments. The specified values in this method should not be taken as the only permanent measurements of values. A simple method is developed based on data with reasonable values to explain this process in general but practical terms.

- *''Which criteria should be taken into account when aggregating from the component to the system level?''*
  The criteria that were identified in this research are material cost, defect cost, safety, environment and aesthetics. The criteria are determined based upon four subsequent steps. Firstly, brainstorm sessions are done in chapter 3.2 to determine potential aggregation criteria from literature. Secondly, literature is consulted in chapter 3.3 to check if these criteria are commonly used and suitable options for aggregating condition scores. Thirdly, interviews are held in chapter 3.4 to gather information about the NEN2767, their experiences within projects and the workability of the NEN-aggregation method. Further, questions about the criteria that can improve and develop the aggregation method are asked. Finally, a selection is held in chapter 3.5 to determine the qualified criteria.

- *''Having identified the relevant criteria, how should these criteria be weighted and aggregated to object and system level?''*
  The criteria are translated into numerical weights by input from the type of defect, condition scores, surface of the components and the uniform table. A uniform table shows the

measures which can be selected to solve or mitigate a defect and their costs. The defects are solved or mitigated by measures from the uniform table. Any safety, environment and aesthetic issue is tackled. The costs for measures and surface system provide weights. By combining total cost and condition scores, weights are produced.

- *''How does the proposed aggregation method perform in relation to the NEN-aggregation method?''*
  The NEN and OCA methods both use inspection results to aggregate, but the data is used differently and this different use of data has an influence on the aggregation results. NEN aggregates all components and estimates renewal costs using the new cost of components. OCA aggregates only components with defects using a uniform table with costs of risk mitigation measures. Therefore, the OCA method produces more critical results than the NEN and is less likely to over or under estimate the aggregated condition. See *Table 15* for a summary of differences.

Table 15 - Similarities and differences of NEN and OCA

NEN2767	OCA
Similarities	
Objectivity	
Inspection results	
Decomposition	
Condition determination	
Differences	
Semi simple, the material cost have to be estimated every single time	Very simple, the measure cost are fixed and can be used every single time
No uniform table for aggregation	Uniform table for aggregation
Different results, because costs need to be determined every single time	Reproducible results through uniform tables
Material cost (costs of the new purchase price of a component)	Measure cost (costs of a measure to solve component defects)
All components are included	Only components with defects are included
Effects of defects are not considered	Effects of defects are solved or mitigated
Serious defects of a small size give low condition scores (1-2)	Low condition scores are tackled by solving these defects with measures
Risks are not solved or mitigated	Risks are solved or mitigated

8.2 Recommendations

This section gives recommendations and proposals for further research.

8.2.1 OCA Method

- The OCA method in this research has aggregated a large group of fixed bridges, but the OCA method is also designed to aggregate a large group of different assets. I recommend to test the applicability of the OCA method for different assets.

- The uniform table is very important in the OCA method. The table proposes fixed measures and cost for each defect. Costs are determined or calculated by help of specific databases and experts. The uniform table in this research is specifically designed for fixed bridges and the data set. I recommend data analysis research of different assets to design new uniform tables. The design of new uniform tables for different assets will further standardize and complement the OCA uniform table database.

8.2.2 Practical implications

8.2.2.1 Surface area & inspection form

- The exact surface area of a defect was or is not yet determined during the inspections currently. Performing exact surface area determination will be more useful, accurate and provide better condition assessment and aggregation. The consequences of determining exact surface are for condition inspection is that more time and resources are required. Research needs to be done on how to educate the inspectors to make accurate estimates, e.g. education, training etc. This research can also be combined with practical exercise to see if accurate estimates are made in practice and to monitor the effects on condition assessment and aggregation.

- The surface system can be added to the inspection form (Appendix XI. Inspection form). This will provide higher accuracy and a step towards standardization will be set if this column is added, see *Figure 9*.

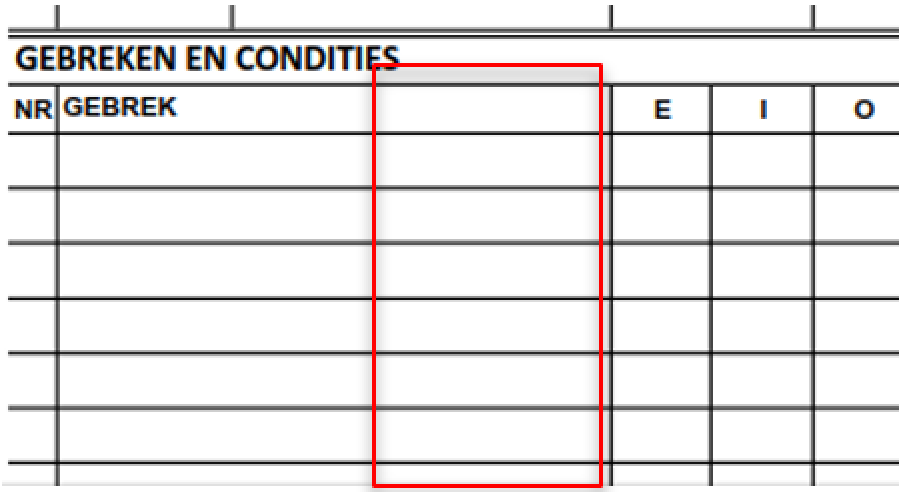

Figure 9 - Partial inspection form, add surface system of defect (red)

8.2.2.2 Surface area determination by inspectors

- Adding surface area to the inspection form brings consequences to generate meaningful data. Data from a condition inspection is extremely important and should be correct. Surface area must be determined in a uniform way by the inspector.

8.2.3 Research proposal

This part gives proposals for further research.

- The OCA can be extended to include different assets in the uniform tables e.g. tunnels, highways etc. This addition will help assess more systems to including a diversity of assets. New sources of inspection data would need to be identified to create new uniform tables that include defects, measures and cost. This will help fill the OCA asset portfolio towards a more complete method.

- The cost often contains uncertainties related to accurate database selection and calculations. The main goal was to estimate an average cost. Therefore, costs contain some expected variance which may lead to over or underestimations. It would be interesting to obtain different cost views and valuations. This will give insight in cost accuracy and provide more accurate condition aggregation.

- The data from the condition measurement is meant to influence maintenance decisions. A standard procedure of how aggregated condition data could be translated to maintenance policy could result in efficiencies in maintenance and provide optimal returns on investment for plans for upcoming years.

- What are the consequences for not solving or mitigating specific defects? Research to produce a risk assessment for defects.

- How can different stakeholders benefit from the OCA and how can it be incorporated in organisations? Convince people, changes in mindset, working methods etc.

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Appendix I. Explanation of aggregation methods in literature

Author(s)	Year	Theory/Method(s)	Explanation	Pro's and Con's
Sylvester Inkoom & John Sobanjo	2018	Availability index Deterioration models	Assess the reliability (up- and downtime) and maintainability properties of and element to assess system performance. Failure and repair rates are important criteria affecting system availability. Historical data of 20 years is used to compute availability and failure of elements. Weibull distribution and Markov transition times modelled the transition time (years to go from condition 1 to 2 etc.) for different conditions (1-5). The results provide a plot of critical component failure, critical component downtime and mean availability. This helps in determining rankings for elements and element weights according to influence on system availability.	Pro's: - Interaction of elements considered - Ranks critical and important elements based on influencing availability - Downtime and failure are considered • Con's: - Sufficient data is necessary - Accuracy could be increased
T. Omar, M. L. Nehdi & T. Zayed	2017	Expert's judgement 9-point Saaty's scale Fuzzy set theory	To determine the weights of common defects occurring in bridge decks the research starts with 17 expert interviews by assessing 1) degree of relative importance for defect and 2) gathering numerical values. Based on a comparison scale the relative importance among defects is gathered to construct comparison matrices. Helps in translating the defects into categories by 1) severity of defects (none-very severe, 5-point scale) and 2) cross section, surface system or length of defect. By using a fuzzy comparison matrix, the results of 17 experts were tackled for uncertainties in judgements, combing these results provide numerical weight values for each	Pro's: - Results are compared and provide insight in accuracy - Tool to prioritize repair and rehabilitation • Con's: - Complex - Time-consuming - Developing new methodology is main idea, not the accuracy of results

			defect. In this way, defects in different categories are aggregated by multiplying weight values and condition categories to gain one aggerated condition score for each category (excellent-poor).	
Sylvester Inkoom, John O. Sobanjo, Paul D. Thompson, Richard Kerr & Richard Twumasi-Boakye	2017	Weighted average	This paper uses a weighted average to calculate the aggregation condition score and assess bridge performance. Steps that are taken: 1) Determine element material costs, long-term costs, vulnerability to hazard risks. 2) Calculate element weight by quantity and unit cost. 3) Combine element weights of material costs, long-term costs, vulnerability to hazard risks by an importance criterion. Extra's considered: 4) Apply amplification weights for elements in bad condition (0-10 adjustment criteria). 5) Linear, non-linear, optimistic, pessimistic condition states (1-5 scale) to show relationship between element condition state weight and extent of deterioration which helps to determine economic value of element.	Pro's: - Cost can be estimated accurately - Risks are included - Elements in bad condition can get extra attention Con's: - Cost-based condition - Reliability of condition scores
Iason Gkountis & Tarek Zayed	2015	Expert's judgement Multi-criteria decision analysis	This research has collected two type of data through online surveys: 1) defect weights and 2) component weights. The condition of components is calculated by inspection data and has received a condition score (A-C). To reach the desired goal, different alternatives are scored on criteria and provide condition indexes for components. The overall condition score is gained by a multi-criteria decision analysis by combining component condition index and component weights.	Pro's: - Several aggregation criteria - Captures interdependence Con's: - Reliability of data - Complex
Hessam Mohseni, Sujeeva Setunge, Guoming	2013	Expert's judgement	Weighting of components is determined by experts with years of experience in knowledge and building maintenance, e.g. building interior counts for 30% of overall building condition score. Another weighting criterion is cost of component.	Pro's: - Reliable results - Easy use

Zhang & Ron Wakefield		Risk-based aggregation	The proposed method for condition aggregation in this paper is risk-based and uses a linear or exponential deterioration curve. The probability of failure for two components is determined and aggregated by weighted averages.	Con's: - Depends on experts capability - Subjective - Used for building elements
Aman Bolar, Solomon Tesfamariam & Rehan Sadiq	2013	HER framework Dempster–Shafer and Yager rule	This hierarchical framework classifies bridge data into primary, secondary, tertiary and life safety-critical elements. The condition parameters (CS 1-5) in combination with reliability criteria aggregate the condition of several elements to a single condition score index by using Dempster–Shafer and Yager formulas.	Pro's: - Classifies elements for their importance - Deals with incomplete and conflicting evidence Con's: - Still needs to be developed further - Suited for bridges - Subjective reliability criteria - Aggregation is complex, due to uncertainty - Correlation of parameters is not considered
Ad Straub	2009	Aggregation	This method weighs the technical status of a component against another component. Weighted average of components is based on hierarchy levels, material cost and is determined by using the Dutch Housing Quality Survey 2000.	Pro's: - Condition index method for all building components - Condition index method for building components which will be replaced and included in maintenance Con's: - Aggregation includes all building components - Aggregated condition and maintenance costs in long-term is not univocal
L. E. Chouinard, G. R. Andersen & V. H. Torrey	1996	Statistical estimation (maximum likelihood etc.)	This paper uses statistical ranking information from an historical database assess the overall condition of civil infrastructure systems. Four models have been developed which provide relative weights, e.g. static and dynamic models based on age and height of a dam in this case.	Pro's: - Rational - Accounts the interaction of components Con's: - Historical database required

Appendix II. Literature review

S. No	Author(s)	Title	Year	Summary	Category
1	Sylvester Inkoom & John Sobanjo	Availability function as bridge element's importance weight in computing overall bridge health index	2018	This research evaluates the availability and criticality of each bridge component or subsystem based on element reliability, failure rates and repair times. By using an availability approach, the importance weights are determined to assess the (overall) health index (of elements). Important criteria to assess performance by finding critical elements are: a) downtime and b) failure. Improving the critical elements help in gaining higher performance (availability and functionality) of bridges.	Aggregation criteria
2	Lucy Quirk, Jose Matos, Jimmy Murphy & Vikram Pakrashi	Visual inspection and bridge management	2018	This research analyses the value of visual inspection strategy for decision-making in a Bridge Management System using a Value of Information methodology. The ability to manage infrastructure successfully is of great importance for economics and competitiveness while having limited resources. A crucial aspect for success is collecting information, information can reduce uncertainty and be an important source for analyzing state of bridges, components and help in decision making. Visual inspection is a first step in providing condition scores for objects, elements and components to predict future conditions, but visual inspection does not provide explicit information about properties or structural components. This article uses an example to show how Value of Information works.	Visual inspection
3	T. Omar, M. L. Nehdi & T. Zayed	Integrated Condition Rating Model for Reinforced Concrete Bridge Decks	2017	This recent paper develops a systematic integrated condition rating for reinforced concrete bridge decks. The aging of reinforced concrete bridge decks causes long term performance issues and is difficult to predict, condition ratings can help tackling these issues. This method uses technology to detect delamination, active corrosion and visual inspection to identify defects in different ways to increase reliability of evaluation and condition rating. The fuzzy set theory is a way for handling uncertainties, a combination of information gathering in above-mentioned techniques provides more reliable condition measurement and scores for the total bridge deck. The article uses an example to show how to apply the condition rating and gain aggregated condition categories (condition rating index).	Rating model aggregation

4	Sylvester Inkoom, John O. Sobanjo, Paul D. Thompson, Richard Kerr & Richard Twumasi-Boakye	Bridge Health Index Study of element Condition States and Importance Weights	2017	This article investigates the condition of bridges based on historical inspection data to support decision making on network and project-level. Three issues are researched to compute bridge health index: 1) Effects of linear and non-linear scales to determine element health index, 2) application of amplification weights to address bridge element in bad condition, 3) development of element weights based on material cost, long-term cost and vulnerability to hazard risks. The use of weight for elements reflects the relative importance of each element. The article concludes with findings for each issue and a way of successfully assessing bridge performance.	Aggregation criteria
5	Maria ANZOLA & Carlos VILA	THE RELEVANCE OF QUALITY DATA MANAGEMENT FOR CONDITION BASED RISK MANAGEMENT	2016	This paper acknowledges the importance of data management in risks-based management and present a system to help in decision making. To deal with asset deterioration, modernization and life extensions strategies an asset management strategy has to be derived from real condition analysis and data to determine interventions for ageing assets. The system provides overall health index based on: a) internal condition, b) external condition, c) design information and d) comments from the business.	Relevant condition data
6	M. Imran Rafiq, Marios K. Chryssanthopoulos & Saenthan Sathananthan	Bridge condition modelling and prediction using dynamic Bayesian belief networks	2015	This paper presents the development of condition-based deterioration method using Bayesian belief network which is a tool to handle complex interdependencies within elements of systems. These systems are composed of interconnected elements to fulfil their function. The availability and reliability of these systems is vital to guarantee certain service and safety levels. Important aspects in systems are: a) deterioration predicting, b) inspection data, c) bridge performance and d) failure probabilities. Inspection results are used as input for the Bayesian belief network to obtain the distribution of overall condition and the dynamic Bayesian belief network is used to incorporate time dependent characteristics.	Condition prediction
7	Iason Gkountis & Tarek Zayed	Subway Infrastructure Condition Assessment	2015	This research develops a method to assess the condition of various components, stations and tunnels based on actual defects. To meet the needs of commuters a fast, reliable and safe mass transit system is required, but such systems show severe deterioration signs. The complexity and importance of these systems require large amount of funds for maintenance and rehabilitation. Therefore, monitoring and assessing condition through a management system is vital. The weights for defects and components are determined by a process involving the goal, alternatives and criteria. To reach the goal different alternatives are considered, these alternatives are scored on criteria and eventually provide the best alternative for reaching the goal (hierarchy multicriteria analysis), an improvement to this method is considering inner and external dependencies (interdependence between criteria). The results are aggregated by a multicriteria decision method where the chosen alternative is closest to the ideal solution, a single condition score for stations and tunnels is calculated.	Aggregation criteria

8	R.P.Y. Mehairjan, Q. Zhuang, D. Djairam & J.J. Smit	Upcoming Role of Condition Monitoring in Risk-Based Asset Management for the Power Sector	2014	This paper explains the importance of condition assessment to manage assets risk-based. To do so, the framework is split into two dimensions: a) strategical, tactical and operational levels, b) technically triggered and non-technically triggered risk. Aspect that can help in condition assessment, maintenance or replacement are: a) asset specific condition data, b) timely condition data and c) predictive condition data. The dimensions and aspects can help in decision-making for improvements, condition assessment and future investment with the available budget.	Risk-based condition management
9	Hessam Mohseni, Sujeeva Setunge, Guoming Zhang & Ron Wakefield	Condition Monitoring and Condition Aggregation for Optimised Decision Making in Management of Buildings	2013	This paper reviews condition monitoring techniques and presents a risk-based methodology for aggregating the inspected condition scores to a higher group level (element, object level), this will help in making strategic decisions. Condition assessment of the asset is influenced by: a) criticality, b) type, c) relative age, d) rate of deterioration and e) economic value of the outcomes to the business. The quality to satisfy the expected function of assets can differ for each type of asset and therefore it is crucial to consider fitness for purpose. Different condition score aggregation methods are proposed: a) an arithmetic mean, b) weighted averages (e.g. cost of component) and c) categorize the criticality of the components (into appearance, consequence of failure and health and safety criteria). The proposed method for condition aggregation in this paper is risk-based and depends on: a) probability of failure, b) condition, c) the associated deterioration curve and d) relative consequence of failure. Based on a linear and exponential deterioration curve of condition, age and probability a condition assessment are made for components. The probability of failure for components are determined and aggregated to determine the condition of an element (combination of components).	Aggregation criteria
10	Aman Bolar, Solomon Tesfamariam & Rehan Sadiq	Condition assessment for bridges: a hierarchical evidential reasoning (HER) framework	2013	This article emphasizes risk-based management to monitor and assess condition of bridge elements for making repairs or replacements before an incident happens. Aging and deterioration of bridge components have led to collapse of several bridges. Therefore, it is challenging to assess the overall condition of bridges with large amounts of data and experts' knowledge. To make this possible fusion of data from several sources is required. This paper proposes to use a hierarchical framework which classifies bridge elements into several groups: a) primary, b) secondary, c) tertiary and d) life safety-critical. A combination of distress indicators, importance and reliability criteria are introduced to aggregate different hierarchy elements.	Rating model aggregation

11	Ad Straub	Dutch standard for condition assessment of buildings	2009	This paper provides insight about the use of a standard condition assessment of buildings by Dutch housing associations. The assessment is scored on a six-point scale and based on importance, intensity and the extent of defects. The assessment results help in the decision-making process of maintenance planning, performance levels and prioritizing maintenance. Aggregated data is of importance for monitoring, benchmarking and budget allocation purposes. The condition scores of components are aggregated by weighing the technical status of a building component against another component. The weights are derived from hierarchical levels and based on the share of the material costs of the total building. Since not all components require maintenance two indicators will be developed: the calculated condition index (includes all components) and a maintenance index (excludes components which will not be replaced or not included in maintenance). Limitations are that condition assessment can't provide annual maintenance budget and planning but supplementary information is required to detect precise location and causes of defects.	Guidelines
12	Nabil Semaan & Tarek Zayed	An infrastructure condition assessment model	2008	In this research a model is developed for condition assessment of subway stations in Montreal, Canada. The functional life and aging are a serious problem in combination with lacking proper rehabilitation planning to guarantee the level of reliability, public safety and level of service. The model has defined hierarchy criteria based on important functions of subway stations and each criterion is scored based on inspection reports. The criteria weights are determined by hierarchical ranking and the aggregation is done by a mathematical outranking method which considers the uncertainties, inaccuracies and incompleteness of information.	Rating model aggregation
13	Abbott, Mc Duling, Parsons, & Schoeman	Building condition assessment: A performance evaluation tool towards sustainable asset management	2007	This paper proposes a condition assessment system and process for sustainable buildings. A five-point condition scale is used, each condition rating provides the required action and type of maintenance (normal and backlog maintenance). The component condition assessment process is based on changes in condition over time, different portions of a component are in different conditions at the same point in time. Therefore, a component is composed of different condition rating scores. The added advantage is not only insight in the actual condition but helps in maintenance budget calculations. The final result is a map showing the average condition of several buildings.	Aggregation criteria
14	Neil S. Grigg	Condition Assessment of Water Distribution Pipes	2006	An example of added value of condition assessment is that it helps in planning renewal programs for systems. The standards and expectations to make decisions keep getting higher while budget is limited. Therefore, effective use of information is key, but a standard for processing large amount of information into an overall condition index is not available yet. This paper collects data from industry, literature survey, workshops and case studies to propose a framework which can help utilities prioritize their repair, rehabilitation and replacement programs with lower cost ways.	Condition framework

15	Ad Straub	Aggregated condition data bridging the gap between property management and asset management	2006	Condition assessment and maintenance planning are key aspects in controlling maintenance performance levels and cost for asset managers. This research is based on 11 case studies about technical and cost data. The relation between aggregated condition scores and maintenance cost is not univocal, because the aggregated scores include all building components even if they don't need maintenance, the weighing of these different components is based on technical state and hierarchy levels.	Guidelines
16	L. E. Chouinard, G. R. Andersen & V. H. Torrey	Ranking Models Used for Condition Assessment of Civil Infrastructure Systems	1996	This paper uses statistical ranking information from an historical database to manage aging infrastructure by prioritizing maintenance and repair cost. The prioritization can be done on the overall condition of civil infrastructure systems by rating each component and combining condition by a weighted summation (reflecting importance based on function). An embankment dam is used as an example and the result of the analysis was that dam age and height had a big influence on the prioritization in ranking. These two parameters have been studied, but the paper says that other important parameters such as reservoir size, fetch should be investigated and included to determine a more accurate condition index.	Rating model aggregation

Appendix III. Interview design in Dutch

Vragen	
Naam – Functie - Ervaring	
Introductie	
	Toestemming
	Introductie interviewer
	Inleiding onderzoek
Interview vragen	
1. Hoe ben je in aanraking gekomen met de NEN 2767?	
	1A. Wat voor soort project?
	1B. Hoe beviel de werkwijze?
2. Kan je mij uitleggen hoe het proces eruit ziet van idee tot toepassing van de NEN2767 in een project?	
	2A. Waar ben jij verantwoordelijk voor in dit proces?
	2B. Hoe worden de resultaten vastgelegd en wat wordt ermee gedaan?
	2C. Wat zijn belangrijke keuzes die vastgelegd worden?
3. Wat wordt er gedaan met de resultaten van de inspecties op bouwdeel niveau?	
	3A. Worden de bouwdeel conditiescores geaggregeerd naar element of object niveau?
	3B. Zo ja, hoe? Zo niet, hoezo niet?
4. De aggregatie wordt gebaseerd op de vervangingskosten van het bouwdeel	
	4A. Wat vind jij hiervan?
	4B. Hoe kan het volgens jou beter? (andere criteriaen)
	4C. Wat vind je van de toegevoegde waarde voor de volgende criteria voor het aggregeren
5. Kunnen de genoemde criteria waarde toevoegen aan het aggregatie proces?	
	5A. Hoe?
	5B. Waarom?
6. Wanneer is een aggregatie tot element en object niveau succesvol voor jou?	
Sluiting	
	Aanbevelingen
	Akkoord gaan met notulen
	Later moment vragen stellen

Beoordeling toegevoegde waarde criteria

		Beoordeling		
Criteria	**Definitie**	**Slecht**	**Gemiddeld**	**Goed**
Vervangingswaarde	Totale kosten in € voor vervanging van bouwdeel.			
Gebrek kosten	Totale kosten in € voor het repareren en/of oplossen van gebreken aan het bouwdeel.			
Veiligheid	Mogelijke veiligheidsrisico's voor gebruikers en werkers door gebreken.			
Functionaliteit	Functionaliteit van het object beïnvloed door gebreken.			
Risico's	Risico's met technische triggers met economische en maatschappelijke impact.			
Omgeving	Schade aan het gebied veroorzaakt door een gebrek.			

		Beoordeling		
Criteria	**Definitie**	**Slecht**	**Gemiddeld**	**Goed**
Beschikbaarheid	Hoe beschikbaar het object in totaliteit is gebaseerd op element geplande/ongeplande onderhoud.			
Betrouwbaarheid	Falen/storingen van de elementen die van invloed zijn op de betrouwbaarheid van het object.			
Veroudering	De snelheid waarmee de conditie van elementen verslechtert (conditievoorspelling)			
Esthetica	Graffiti, vegetatie en vervuiling van het element dat de esthetiek van het object beïnvloedt.			

Vragen	
Ben Visser – Projectleider Assetmanagement Kunstwerken – 2 Jaar	
Introductie	
1. Als projectleider AM kreeg ik de vraag hoe beheerders hun assets op een effectieve wijze kunnen beheren.	
	1A. Adviesprojecten gericht op inspectie, decompositie, onderhoud, beleid, wetgeving, kwaliteit en budget.
	1B. Aardig/goed, omdat de NEN2767 de gebreken van een bouwdeel op uniforme wijze vast kan leggen.
2. Vaak komt de vraag van de opdrachtgever om te bepalen hoe het systemal eraan toe is. Het proces ziet er uit als volgt: 1. vraag over systemal, 2. Aangeven hoe die er wordt ingegaan op de gebreken, 3. inspecties van kunstwerken, 4. vastleggen inspectie resultaten, 5. controleren van de resultaten en in stap 6 worden de onderhoudsmogelijkheden besproken.	
	2A. Ik als projectleider ben verantwoordelijk voor het in goede orde leiden van het projecten en let daarbij op tijd, kwaliteit en budget.
	2B. De inspectieresultaten worden vastgelegd op een tablet/formulier, geconverteerd naar een Excel sheet en vervolgens ingevoerd in een beheersysteem.
	2C. Belangrijke keuzes die vastgelegd worden zijn de paspoortgegevens, decompositie, gebreken en onderhoudsplan.
3. De conditiescores voor de bouwdelen worden meegenomen in de analyse voor de volgende thema's: veiligheid, aanzien, duurzaamheid en functionaliteit. Dit wordt gedaan om maatregelen te treffen voor de risico's die verbonden zijn aan bovengenoemde thema's.	
	3A. Nee, dat doen wij nog niet
	3B. De aggregatie gebaseerd op vervangingswaarde is duidelijk, maar niet accuraat. Totaal verschillende bouwdelen met verschillende functies worden vergeleken gebaseerd op vervangingswaarde.
4. De aggregatie wordt gebaseerd op de vervangingskosten van het bouwdeel.	
	4A. De aggregatie gebaseerd op vervangingswaarde is duidelijk, maar niet accuraat. Totaal verschillende bouwdelen met verschillende functies worden vergeleken gebaseerd op vervangingswaarde.
	4B. Meerdere criteria en betrekken in het proces van aggregeren. Dit kunnen zijn: functioneren, aanzien, duurzaamheid en veiligheid.
	4C. Vervangingswaarde (Goed), Gebrek kosten (Goed), Veiligheid (Gemiddeld), Functionaliteit (Gemiddeld), Risico's (Gemiddeld), Omgeving (Slecht), Beschikbaarheid (Slecht), Betrouwbaarheid (Gemiddeld), Veroudering (Slecht), Esthetica (Gemiddeld).
5. Ja	
	5A. De vergelijking tussen de bouwdelen kan gemaakt worden door de effecten op verschillende criteria en te bepalen. Dit geeft een beter beeld van de invloeden die worden veroorzaakt door gebreken.
	5B. De meetbaarheid van de criteria en zijn van cruciaal belang, omdat die de reproduceerbaarheid beïnvloeden en de aggregatie uitvoerbaar houd.
6. Als ik op een onderbouwde manier kan volgen hoe de aggregatie uitgevoerd word om de toestand en kwaliteit van het systemal te bepalen.	
Sluiting	

Vragen	
Roel Warringa – Directeur Helix / Rapporteur NEN2767 – 40 Jaar	
Introductie	
1. Ik heb samen met de Rijksgebouwendienst contact gezocht met de NEN om de NEN2767 op te starten.	
	1A. In samenwerking met Witteveen+Bos hebben wij een conditiemeting gedaan voor de Gemeente Gouda.
	1B. Goed, alleen de kwaliteit en eisen die opdrachtgevers vanuit de infra stellen is laag. Hogere kwaliteit en eisen mogen gesteld worden.
2. Het is belangrijk om het doel van de vraag te achterhalen. De volgende stappen worden doorlopen: 1. Vraag begrijpen (wat wil je bereiken met de NEN2767), 2. Conditiemeting uitvoeren (1x in 3 jaar), 3. Resultaten in een beheersysteem invoeren, 4. De benodigde activiteiten bepalen, 5. Jaarplan opstellen, 6. Evaluatie en 7. Planning bijstellen na evaluatie.	
	2A. Ik ben als directeur verantwoordelijk voor de offertes. In projecten let ik op kwaliteit, tijd en geld.
	2B. Er zijn 8 verschillende systemen voor de infra waarin de inspectieresultaten kunnen worden vastgelegd
	2C. Belangrijke keuzes die vastgelegd worden zijn: hoe de inspectie uitgevoerd moet worden, de diepgang van de inspectie (dieper maakt het lastiger), het niveau van de inspecteurs (goed opgeleid) en een correcte decompositie.
3. Er moet eerst bepaald worden wat de prioriteiten zijn. Vervolgens wordt er gekeken naar de toelaatbaarheid van de conditie in combinatie met relevante aspecten.	
	3A. Ja, maar dit hangt voornamelijk af van de beheerder.
	3B. Op basis van vervangingskosten voor bouwdelen wordt er geaggregeerd.
4. De aggregatie wordt gebaseerd op de vervangingskosten van het bouwdeel.	
	4A. Ik vind het een goed en eenvoudig methode. De begrijpbaarheid om de methode uit te voeren met simpel zijn voor de gemiddelde beheerder. Wat wel belangrijk is om te onthouden over de aggregatie is dat bouwdelen die geen onderhoud nodig hebben niet deel moeten uitmaken van de aggregatie. Een bouwdeel dat geen invloed heeft moet ook niet meegenomen worden.
	4B. Selecteren van onderhoud behoevende bouwdelen, meenemen van aspecten benoemd in bijlage D en RAMSSHEEP.
	4C. Vervangingswaarde (Goed), Gebrek kosten (Slecht), Veiligheid (Goed), Functionaliteit (Goed), Risico's (Gemiddeld), Omgeving (Goed), Beschikbaarheid (Gemiddeld), Betrouwbaarheid (Gemiddeld), Veroudering (Slecht), Esthetica (Goed).
5. Ja	
	5A & 5B. Wat vooral belangrijk is als je dergelijk criteria gaat gebruiken is dat deze meetbaar moeten zijn. De eenvoudigheid om de methode toe te passen is van cruciaal belang, omdat een gebruiker of beheerder moet kunnen begrijpen hoe het werkt.
6. Voor mij is een aggregatie succesvol als ik 5 jaar later iets kan zeggen over de ontwikkeling van de conditie. Verschillen wil ik graag zien, om te bepalen of de genomen maatregelen de conditie hebben verslechterd of verbeterd.	
Sluiting	

Vragen	
Douwe Schoonderwaldt – Senior Adviseur Assetmanagement – 15 Jaar	
Introductie	
1. In 2009 was ik manager beheer en onderhoud bij Movares en heb ik een oproep gekregen van de NEN om de gebouwen norm te transformeren naar een infra norm.	
	1A. Mijn eerst project was een pilot inspectie bij de gemeente Limburg om te bepalen of de conditie juist wordt bepaald. We hebben geconstateerd dat de criteria 'omvang' veel invloed heeft op de conditiescores.
	1B. De NEN2767 inspectie is een totale verandering ten opzichte van de traditionele manier van inspecteren. Het was lastig voor de inspecteurs om de conditie objectief te bepalen met de NEN2767.
2. Het proces start met de reden waarom je de conditie van het systemal wilt bepalen. Vervolg stappen zijn: 1. Vaststellen op welk niveau de conditiemeting gedaan moet worden, 2. Het geselecteerde niveau vertalen tot een correcte decompositie.	
	2A. Ik was als interim assetmanager verantwoordelijk voor het instandhouden van civiele kunstwerken voor de gemeente Amsterdam.
	2B. Meestal worden de resultaten van de inspecties aangeleverd in Excel en ingevoerd in een beheersysteem. Vervolgens kunnen de conditiescores geaggregeerd worden op basis van vervangingswaarde.
	2C. Belangrijke keuzes die vastgelegd worden zijn: een correcte decompositie en welke vervangingswaarde gebruikt moet worden.
3. Voor de harde infra (bruggen, tunnels, duikers etc.) worden de inspecties gedaan op bouwdeel niveau. De resultaten worden niet gebruikt voor aggregaties. Bij waterkering wordt de aggregatie wel gebruikt.	
	3A. Nee, veel beheerders gebruiken de gewogen gemiddelde. Dit is geen onderdeel van de NEN en in principe als aggregatie methode dus fout.
	3B. Vele beheerders verdiepen zich niet in de aggregatie, omdat deze de vervangingswaarde als aggregatiecriteria niet willen.
4. De aggregatie wordt gebaseerd op de vervangingskosten van het bouwdeel.	
	4A. Goed, omdat de 'belangrijke' bouwdelen van een object vaak het meeste invloed hebben op het functioneren van het object. Dus in principe is een bouwdeel dat meer kost 'belangrijker' en weegt daardoor zwaarder mee in de aggregatie.
	4B. Bedrijfswaarden kunnen een belangrijke bijdrage leveren aan het verbeteren/uitbreiden van de aggregatie. Waarden zoals duurzaamheid, aanzien, heel en schoon etc.
	4C. Vervangingswaarde (Goed), Gebrek kosten (Goed), Veiligheid (Gemiddeld), Functionaliteit (Slecht), Risico's (Slecht), Omgeving (Gemiddeld), Beschikbaarheid (Goed), Betrouwbaarheid (Goed), Veroudering (Slecht), Esthetica (Gemiddeld).
5. Ja.	
	5A & 5B. Zolang het normatief te bepalen is en te vertalen of koppelen is aan richtlijnen. Functionaliteit zit al in methode van inspectie en risico's bepalen aan de hand van conditie is een vervolgstap van assetmanagement
6. Als het een objectief beeld geeft van het functioneren op element en objectniveau.	
Sluiting	

Vragen	
Nico Broek – Senior Adviseur Beheer & Onderhoud – 20 Jaar	
Introductie	
1. Ongeveer 10 jaar geleden heb ik op social media gezien dat er een nieuwe objectieve methode is voor het meten van kunstwerken condities. Twee jaar na het vormen van de commissie ben ik lid geworden van een werkgroep	
	1A. Mijn eerste project was een inspectie. Hiervoor moesten we een decompositie maken en de gebreken bepalen.
	1B. De norm is tot stand gekomen door de grotere spelers, zoals Rijkswaterstaat en provincies. Vooral gericht op grotere objecten. Er was geen aansluiting vanuit de gemeentes om deel te nemen aan de ontwikkeling van de norm. Hierdoor was het lastiger om de norm toe te passen voor de objecten van gemeentes, de termen die werden gebruikt maakten dit nog lastiger.
2. Mijn eerste project was voor de provincie Zuid-Holland. De provincie had zijn eigen decompositie gemaakt los van de NEN2767. Vervolgens moest ik inspecteren volgens de NEN2767 om de gebreken te bepalen.	
	2A. Ik was verantwoordelijk voor het binnenhalen van werk, de voorbereiding, uitvoering van de inspectie en verwerking van de resultaten.
	2B. In het project voor de provincie Zuid-Holland werden de resultaten verwerkt in een Excel bestand. Vervolgens werden de bestanden gebruikt voor het maken van contracten om werkzaamheden door de markt uit te laten voeren.
	2C. Het gebrek vanuit de NEN2767 correct bepalen. De conditiescores bepalen aan de hand van omvang, intensiteit en ernst. Goed opgeleide inspecteurs spelen een cruciale rol hierbij.
3. In het project voor de provincie Zuid-Holland werden de resultaten verwerkt in een Excel bestand. Vervolgens werden de bestanden gebruikt voor het maken van contracten om werkzaamheden door de markt uit te laten voeren.	
	3A. Nee
	3B. Het kost de beheerder veel geld om een aggregatie te laten uitvoeren. Los van de inspectie kan dat vijf keer zoveel kosten. Een beheerder kijkt naar wat die nodig heeft en wat die met een aggregatie gebaseerd op vervangingswaarde kan.
4. De aggregatie wordt gebaseerd op de vervangingskosten van het bouwdeel.	
	4A. De aggregatie is te beperkt, omdat deze alleen de vervangingswaarde gebruikt terwijl er meerdere criteria en invloed hebben. In de praktijk werkt het niet, dus ik heb er niet veel aan.
	4B. De aggregatie meer baseren op gevolgschade die voortkomt uit een gebrek.
	4C. Vervangingswaarde (Goed), Gebrek kosten (Goed), Veiligheid (Goed), Functionaliteit (Goed), Risico's (Goed), Omgeving (Goed), Beschikbaarheid (Goed), Betrouwbaarheid (Gemiddeld), Veroudering (Slecht), Esthetica (Slecht).
5. Ik vind dit een lastige vraag en heb geen antwoord hiervoor.	
	5A & 5B. Ik vind dit een lastige vraag en heb geen antwoord hiervoor.
6. Een aggregatie is succesvol als deze goed onderbouwd is en ik snap waarom de aggregatie op een bepaalde manier gedaan word. Ook is deze succesvol als de beheerder zich daarin kan vinden.	
Sluiting	

Appendix IV. Case study information

Object A

Figure 10 - Wooden Bridge Side View

Decomposition

The wooden bridge consists of several elements and components as seen in *Table 22* and *Figure 11*. The elements are: anti-vandalism provision, main supporting structure, handrail construction, wear layer and support. The components are: fence, longitudinal beam, l, pole, drive deck, handrail, wear layer (general) and support (general). The last two elements are wear layer and support. These elements cannot be further decomposed in components. Therefore, 'general' is added to make a decomposition at the component level possible.

Found Defects of Component

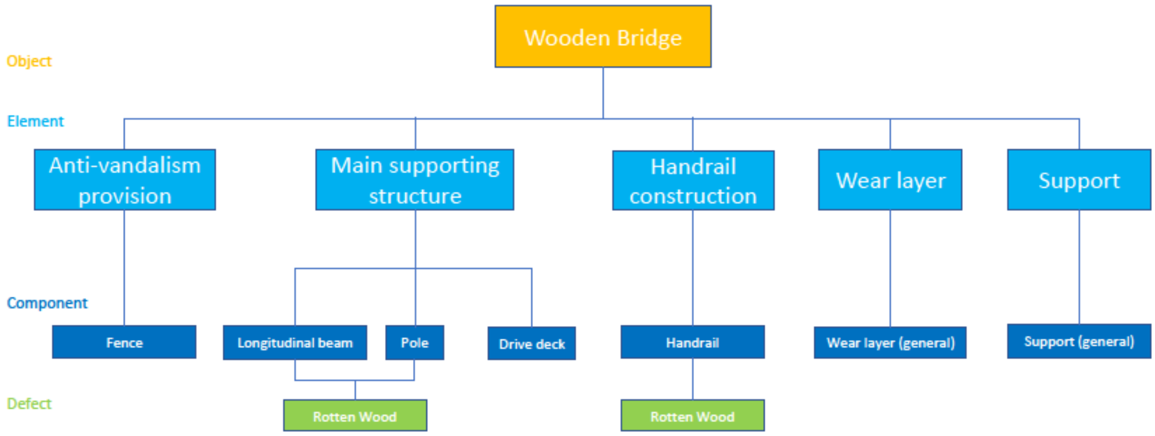


Figure 11 - Schematic Decomposition of Wooden Bridge

During inspection, three defects (*Table 23*) have been found by an inspector. Two defects for the main supporting structure and one for the handrail construction. Based on the seriousness, size and intensity the components are scored. This resulted in condition score 2 (incidental aging has started) for the longitudinal beam (*Figure 12*) and handrail (*Figure 14*). A condition score of 6 (candidate for demolition) was generated for the pole (*Figure 13*).

Figure 12 - Longitudinal Beam

Figure 13 - Pole

Figure 14 - Handrail

Criteria

The criteria is discussed in Chapter 4.4.

Table 16 - Aggregation Criteria

Component	Material cost	Defect cost	Safety	Environment	Aesthetics
Fence					
Longitudinal beam					
Pole					
Drive deck					
Handrail					
Wear layer (general)					
Support (general)					

Material cost

The cost of replacing a component.

Defect cost

The cost of solving or mitigating a defect.

Safety

The safety of the wooden bridge is important and any potential defects in the components should be considered as a priority. Therefore, defects of components causing safety issues will be determined.

Environment

The bridge is the only link between a residential system and a school as seen in *Figure 15*, any serious defect can cut of accessibility of the school. Thus, the consequences of any decisions affecting the environment are important. Leaving future generations with an equal or better environment is essential. Accessibility, quality of life in the system and any nuisances will be considered. Therefore, any defects of the components causing that cause harm to the environment will be determined.

Figure 15 - Satellite view of area

Aesthetics

The aesthetics of objects are representative of the system and should be maintained at agreeable levels. Graffiti, vegetation and pollution affecting object aesthetics will be considered.

Object B

Figure 16 - Bottom View Concrete Bridge

Decomposition

The concrete bridge consist of several elements and components as seen in *Table 24* and *Figure 17*. The elements are: guide construction, main supporting structure, rainwater drainage, handrail construction, bearing, support, slope and expansion joint. The components are: guiderail, main supporting structure (general), beam, arch, drive deck, drain, pond, handrail, bearing (general), pillar, abutment, support beam, foundation block, slope (general), revetment, sealing strip and expansion joint (general).

Found Defects of Components

During inspection six defects (*Table 25*) have been found by an inspector. All six defects are for the main supporting structure. Based on the seriousness, size and intensity the components are scored. This resulted in a condition score 1 (incidentally minor defects) for the arch and drive deck. A condition score of 3 (locally visible aging, function fulfillment of building and installation parts is not occasionally in danger) for the main supporting structure (general). See figures below for impression.

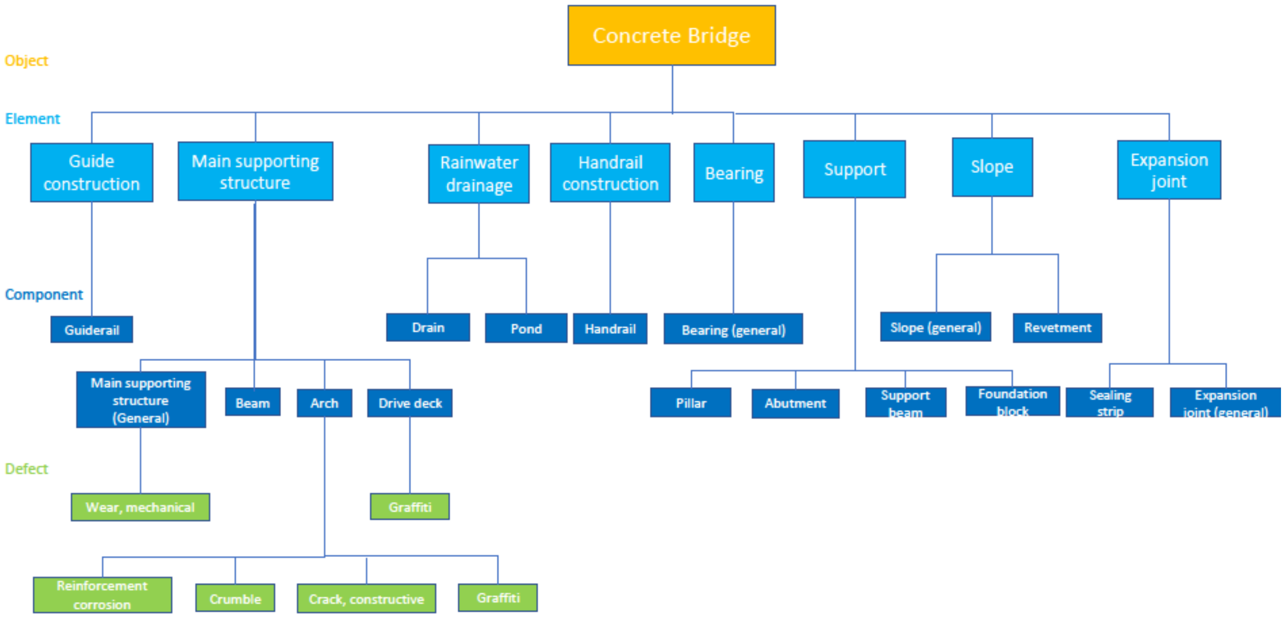


Figure 17 - Schematic Decomposition of Concrete Bridge

Figure 18 - Reinforcement corrosion

Figure 19 - Crumble 1

Figure 20 - Crumble 2

Figure 21 - Crumble 3

Figure 22 - Crack, constructive 1

Figure 24 - Crack, constructive 2

Figure 23 - Crack, constructive 3

Figure 25 - Graffiti

Figure 26 - Wear, mechanical 1

Figure 27 - Wear, mechanical 2

Figure 28 - Drive deck

Aggregation Criteria

The aggregation criteria which will be considered are material cost, defect cost, safety, environment and aesthetics. Each criterion is analyzed in Chapter 4.5.

Table 17 - Aggregation Criteria

Component	Material cost	Defect cost	Safety	Environment	Aesthetics
Guiderail					
Main supporting structure (General)					
Beam					
Arch					
Drive deck					
Drain					
Pond					
Handrail					
Bearing (General)					
Pillar					
Abutment					
Support beam					
Foundation block					
Slope (General)					
Revetment					
Sealing strip					
Expansion joint (General)					

Material cost

The cost of replacing a component.

Defect cost

The cost of solving a defect.

Safety

The safety of the wooden bridge is important and any potential defects in the components should be considered as a priority. Therefore, defects of components causing safety issues will be determined.

Environment

The bridge is part of a provincial highway providing possibilities for mixed traffic and the road connects Roermond with the German border near Posterholt before the route continues to Heinsberg. The road is 11 kilometers long as seen in *Figure 29* and *Figure 30*. Any serious defect can cut off the accessibility of the system and create a nuisance. The consequences of decisions on the environment within projects is becoming more important. Leaving future generations with an equal or better environment is essential. Accessibility, the quality of life in the system and any potential nuisance will be considered. Therefore, defects in components causing harm to the environment will be determined.

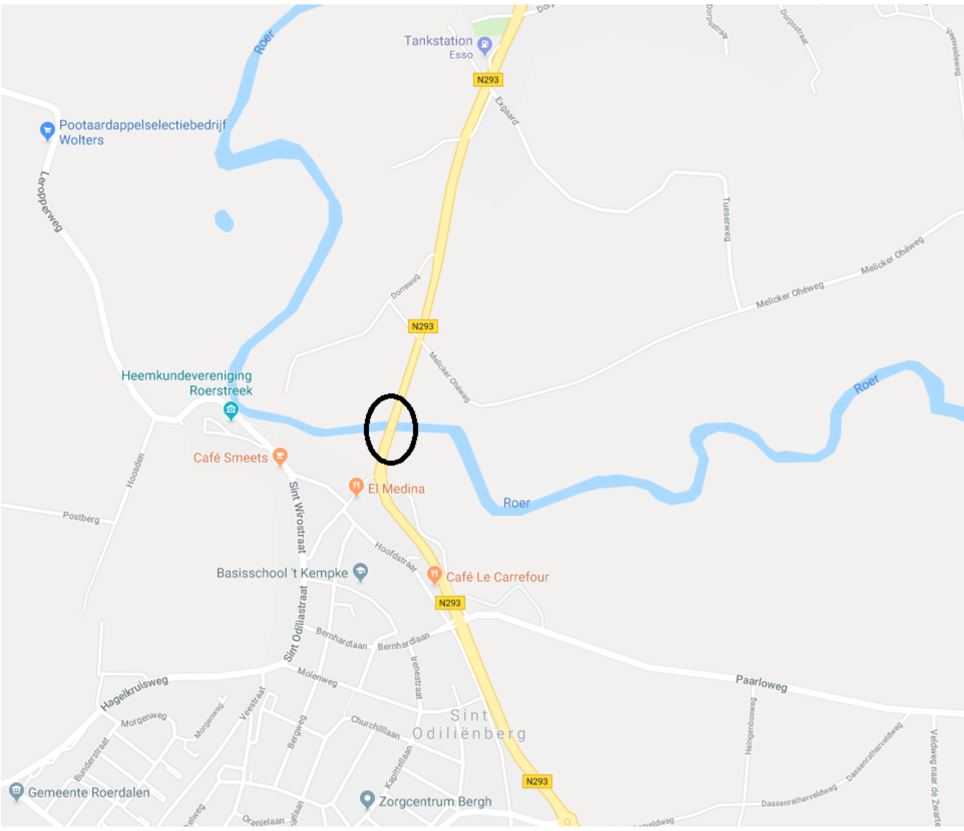


Figure 29 - Satellite view of area

Figure 30 - Satellite view connecting roads

Aesthetics

The aesthetics of objects are representative for the system and should be maintained at agreeable levels. Graffiti, vegetation and pollution affecting object aesthetics will be considered.

Appendix V. Example NEN2767 inspection

In this part an example will be shown about how inspection provides condition scores.

Inspection

The inspection is conducted on the component level. The inspector looks for defects and scores them on the following aspects and *Figure 31*:

- Seriousness.
- Size.
- Intensity.

Conditionscore NEN2767						
Defect		< 2% incidental	2 - 10 % local	10 - 30 % regularly	30 - 70 % considerably	> 70 % general
	Intensity					
low	start	1	1	1	1	2
	advanced	1	1	1	2	3
	end	1	1	2	3	4
serious	start	1	1	1	2	3
	advanced	1	1	2	3	4
	end	1	2	3	4	5
important	start	1	1	2	3	4
	advanced	1	2	3	4	5
	end	2	3	4	5	6

Figure 31 - Condition table (NEN, 2017)

Inspection example of component A according to Figure 31:

- The seriousness of the defect is important.
- The size of the defect is 10-30% regularly.
- The intensity of the defect is end.
- The seriousness, size and intensity combination leads to a condition score of 4.

Appendix VI. Example NEN2767 and OCA aggregation to object and system level

This appendix treats **fictive** examples to demonstrate the NEN2767 and OCA aggregation to object and system level. Steps are described in chapter 4.2, 4.3, 5.2 and 5.3.

NEN2767 aggregation steps to object level

1. The scope of this aggregation is two assets.
2. The decomposition of object 1 and 2 is provided in *Figure 32* and *Figure 33*. Object 1 has three elements and five components. Object 2 has two elements and four components. Now, the inspector has an overview of the objects.

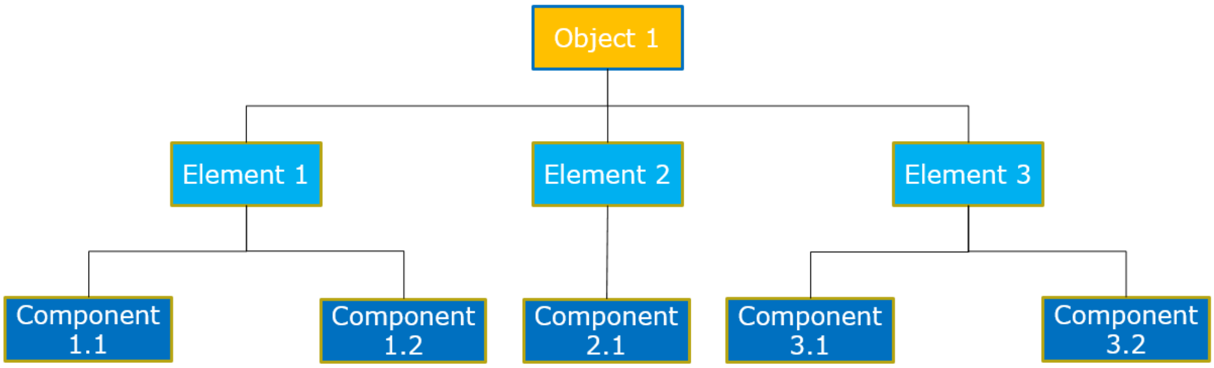


Figure 33 - Decomposition of object 1

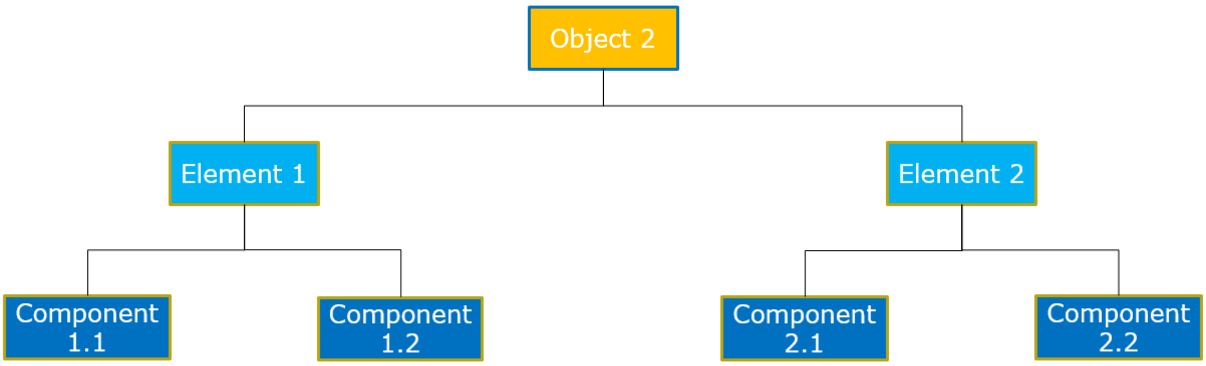


Figure 32 - Decomposition of object 2

3. The inspector inspects the components of the objects visually by analyzing three aspects: seriousness, size and intensity of the defects.
4. The inspections from step 3 provides condition scores on component level for object 1 and 2:

			Condition score (1-6)
Object 1	Element 1	Component 1.1	2
		Component 1.2	3
	Element 2	Component 2.1	1
	Element 3	Component 3.1	1
		Component 3.2	5

			Condition score (1-6)
Object 2	Element 1	Component 1.1	5
		Component 1.2	1
	Element 2	Component 2.1	2
		Component 2.2	4

5. The material cost of every component from step 4 is determined in euro's. These are the costs to purchase the exact same materials.

		Material cost (€)
Object 1	Component 1.1	7000
	Component 1.2	1500
	Component 2.1	5000
	Component 3.1	1000
	Component 3.2	2000

		Material cost (€)
Object 2	Component 1.1	3500
	Component 1.2	2500
	Component 2.1	4000
	Component 2.2	6000

6. Now the aggregation to element level can start by using *Table 18*. Firstly, each condition score is converted to a correction factor. In the tables below an overview is given of the decomposition, condition scores, correction factors and material cost. The aggregation starts with multiplying correction factors with material costs to gain the result of the elements.

Table 18 - Correction factors (NEN, 2017)

Condition score	Correction factor
1	1,0
2	1,02
3	1,1
4	1,3
5	1,7
6	2,0

			Condition score	Correction factor	Material cost (€)
Object 1	Element 1	Component 1.1	2	1,02	7000
		Component 1.2	3	1,1	1500
	Element 2	Component 2.1	1	1,0	5000
	Element 3	Component 3.1	1	1,0	1000
		Component 3.2	5	1,7	2000

					Material cost (€)
Object 2	Element 1	Component 1.1	5	1,7	3500
		Component 1.2	1	1,0	2500
	Element 2	Component 2.1	2	1,02	4000
		Component 2.2	4	1,3	6000

Object 1 result aggregation element 1 = $\frac{7000*1,02+1500*1,1}{7000+1500} = 1,03.$

Object 1 result aggregation element 2 = $\frac{1500*1,0}{1500} = 1,0.$

Object 1 result aggregation element 3 = $\frac{1000*1,0+2000*1,7}{1000+2000} = 1,47.$

Object 2 result aggregation element 1 = $\frac{3500*1,7+2500*1,0}{3500+2500} = 1,41.$

Object 2 result aggregation element 2 = $\frac{4000*1,02+6000*1,3}{4000+6000} = 1,19.$

7. The element result scores in step 6 are converted with *Table 19*. Each result has a condition score from 1 to 6, e.g. result 1.45 is condition score 5 according to *Table 19*.

Table 19 - Condition determination (NEN,

Condition determination	
Result	**Condition score**
Result ≤ 1,01	1
1,01 < Result ≤ 1,04	2
1,04 < Result ≤ 1,15	3
1,15 < Result ≤ 1,4	4
1,4 < Result ≤ 1,78	5
Result ≥ 1,78	6

The results of the conversion of the element result scores from step 6 to element condition scores are as follows:

Object 1 result aggregation element 1 = 1,03, element condition score = 2

Object 1 result aggregation element 2 = 1,0, element condition score = 1

Object 1 result aggregation element 3 = 1,47, element condition score = 5

Object 2 result aggregation element 1 = 1,41, element condition score = 5

Object 2 result aggregation element 2 = 1,19, element condition score = 4

8. Now the element condition scores are aggregated to object result scores. The element condition scores which are determined in step 7 are converted to the correction factors. The

material cost of components are summed up in the tables below. Now, the elements are aggregated by multiplying element material cost with correction factors.

		Condition score	Correction factor	Material cost (€)
Object 1	Element 1	2	1,02	7000 + 1500 (component 1 + 2)
	Element 2	1	1,0	5000
	Element 3	5	1,7	1000 + 2000 (component 1 + 2)

		Condition score	Correction factor	Material cost (€)
Object 2	Element 1	5	1,7	3500 + 2500 (component 1 + 2)
	Element 2	4	1,3	4000 + 6000 (component 1 + 2)

Result aggregation object 1 = $\frac{8500*1,02+5000*1,0+3000*1,7}{8500+5000+3000}$ = 1,14.

Result aggregation object 2 = $\frac{6000*1,7+10000*1,3}{6000+10000}$ = 1,45.

9. The object result score is converted by *Table 19* condition determination.

   Result object 1 aggregation = 1,14, object 1 condition score = 3

   Result object 2 aggregation = 1,45, object 2 condition score = 5

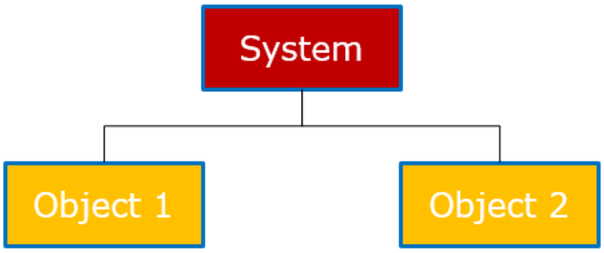
10. The final result is the aggregated condition score of the objects. Object 1 has condition score 3. Object 2 has condition score 5.

1	2	3	4	5	6
Excellent	Good	Reasonable	Moderate	Bad	Very bad

NEN2767 aggregation steps to system level

The aggregation from object to system level is done by adding two extra steps to the aggregation steps from component to object level:

10. The system result score is the aggregation from object to system level and base on the object decomposition, object condition scores, object material cost and correction factors. The decomposition shows the system and its objects. The table provides the condition score, correction factor and material cost of the objects.



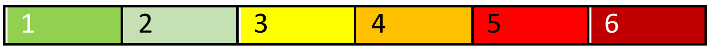
		Condition score	Correction factor	Material cost (€)
System	Object 1	3	1,1	8500 + 5000 + 3000 (element 1 + 2 + 3)
	Object 2	5	1,7	6000 + 10000 (element 1 + 2)

System aggregation result score = $\frac{16500*1,1+16000*1,7}{16500+16000}$ = 1,40.

11. The system condition score is converted by *Table 19* condition determination.

    System aggregation result score = 1,40, system condition score = 4

12. The final result of the system is condition score 4



OCA aggregation steps to object level

1. The scope of this aggregation is two assets.
2. The decomposition of object 1 and 2 is provided in *Figure 32* and *Figure 33*. Object 1 has three elements and five components. Object 2 has two elements and four components. Now, the inspector has an overview of the objects.

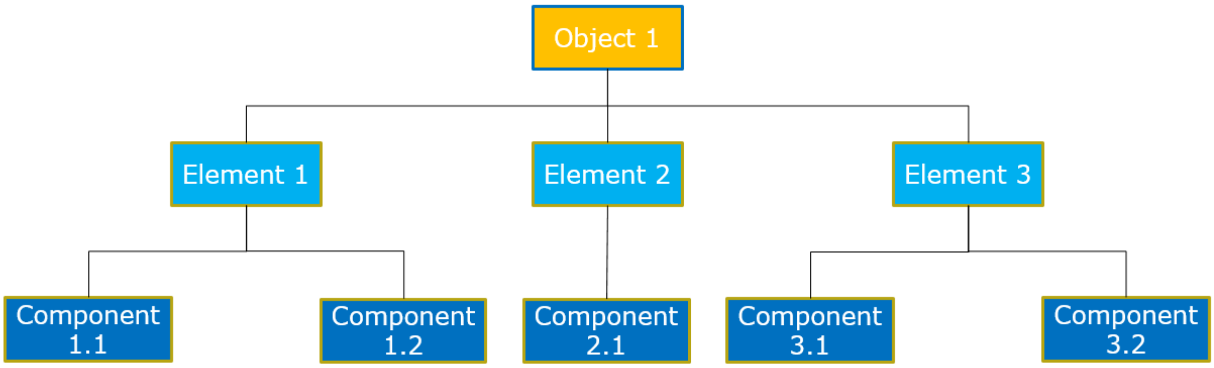


Figure 35 - Decomposition of object 1

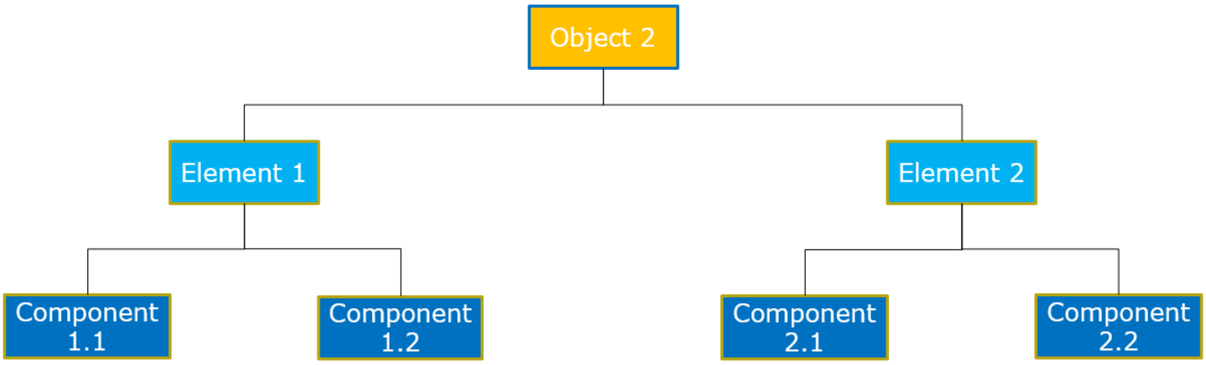


Figure 34 - Decomposition of object 2

3. The inspector inspects the components of the objects visually by analyzing three aspects: seriousness, size and intensity of the defects.
4. The inspections from step 3 provides condition scores on component level for object 1 and 2:

			Condition score (1-6)
Object 1	Element 1	Component 1.1	2
		Component 1.2	3
	Element 2	Component 2.1	1
	Element 3	Component 3.1	1
		Component 3.2	5

			Condition score (1-6)
Object 2	Element 1	Component 1.1	5
		Component 1.2	1
	Element 2	Component 2.1	2
		Component 2.2	4

5. This uniform table is fictive and built by considering all components of the objects and their defects to propose measures to solve and/or mitigate each defect. In Appendix IX. the uniform table designed for this research is given.

Component	Defect	Measure	Cost (in euro)	Unit
Component 1.1	Defect 1.1	Measure 1.1	150	m
Component 1.2	Defect 1.2	Measure 1.2	50	piece
Component 2.1	Defect 2.1	Measure 2.1	100	m3
Component 3.1	Defect 3.1	Measure 3.1	50	m2
Component 3.2	Defect 3.2	Measure 3.2	30	m2
Component 1.1	Defect 1.1	Measure 1.1	100	1
Component 1.2	Defect 1.2	Measure 1.2	70	m2
Component 2.1	Defect 2.1	Measure 2.1	10	m2
Component 2.2	Defect 2.2	Measure 2.2	80	m3

6. Now, the table in step 5 makes it possible to select a measure for all component defects. For each defect a measure and cost can be found in the table.
7. The affected surface area of the component by the defect is determined. The defects cover a certain percentage of the surface area of components. This area has to be determined in m2, m3 or any other unit during inspections.

		Surface area	Unit	Cost (in euro)
Object 1	Component 1.1	100	m	150
	Component 1.2	10	piece	50
	Component 2.1	30	m3	100
	Component 3.1	20	m2	50
	Component 3.2	10	m2	30

		Surface area	Unit	Cost (in euro)
Object 2	Component 1.1	1	1	100
	Component 1.2	100	m2	70
	Component 2.1	8	m2	10
	Component 2.2	10	m3	80

8. The total costs of the selected measures is calculated by multiplying measure cost and surface area of the components.

Object 1:

Component 1.1 $= 100 * 150 = €15000$

Component 1.2 $= 10 * 50 = €500$

Component 2.1 $= 30 * 100 = €3000$

Component 3.1 $= 20 * 50 = €1000$

$\text{Component 3.2} = 10 * 30 = €300$

Object 2:

$\text{Component 1.1} = 1 * 100 = €100$

$\text{Component 1.2} = 100 * 70 = €7000$

$\text{Component 2.1} = 8 * 10 = €80$

$\text{Component 2.2} = 100 * 80 = €800$

9. Now the aggregation to element level can start by using *Table 18*. Firstly, each condition score is converted to a correction factor. In the tables below an overview is given of the decomposition, condition scores, correction factors and material cost. The aggregation starts with multiplying correction factors with material costs to gain the result of the elements.

Table 20 - Correction factors (NEN, 2017)

Condition score	Correction factor
1	1,0
2	1,02
3	1,1
4	1,3
5	1,7
6	2,0

			Condition score	**Correction factor**	**Measure cost (€)**
Object 1	Element 1	Component 1.1	2	1,02	15000
		Component 1.2	3	1,1	500
	Element 2	Component 2.1	1	1,0	3000
	Element 3	Component 3.1	1	1,0	1000
		Component 3.2	5	1,7	300

					Material cost (€)
Object 2	Element 1	Component 1.1	5	1,7	100
		Component 1.2	1	1,0	7000
	Element 2	Component 2.1	2	1,02	80
		Component 2.2	4	1,3	800

Object 1 result aggregation element 1 = $\frac{15000*1{,}02+500*1{,}1}{15000+500}$ = 1,02.

Object 1 result aggregation element 2 = $\frac{3000*1{,}0}{3000}$ = 1,0.

Object 1 result aggregation element 3 = $\frac{1000*1{,}0+300*1{,}7}{1000+300}$ = 1,16.

Object 2 result aggregation element 1 = $\frac{100*1,7+7000*1,0}{100+7000}$ = 1,01.

Object 2 result aggregation element 2 = $\frac{80*1,02+800*1,3}{80+800}$ = 1,27.

10. The element result scores in step 6 are converted with *Table 19*. Each result has a condition score from 1 to 6, e.g. result 1.45 is condition score 5 according to *Table 19*.

Table 21 - Condition determination (NEN,

Condition determination	
Result	**Condition score**
Result ≤ 1,01	1
1,01 < Result ≤ 1,04	2
1,04 < Result ≤ 1,15	3
1,15 < Result ≤ 1,4	4
1,4 < Result ≤ 1,78	5
Result ≥ 1,78	6

The results of the conversion of the element result scores from step 6 to element condition scores are as follows:

Object 1 result aggregation element 1 = 1,02, element condition score = 2

Object 1 result aggregation element 2 = 1,0, element condition score = 1

Object 1 result aggregation element 3 = 1,16, element condition score = 4

Object 2 result aggregation element 1 = 1,01, element condition score = 1

Object 2 result aggregation element 2 = 1,27, element condition score = 4

11. Now the element condition scores are aggregated to object result scores. The element condition scores which are determined in step 7 are converted to the correction factors. The material cost of components are summed up in the tables below. Now, the elements are aggregated by multiplying element material cost with correction factors.

		Condition score	**Correction factor**	**Material cost (€)**
Object 1	Element 1	2	1,02	15000 + 500 (component 1 + 2)
	Element 2	1	1,0	3000
	Element 3	4	1,7	1000 + 300 (component 1 + 2)

		Condition score	Correction factor	Material cost (€)
Object 2	Element 1	1	1,0	100 + 7000 (component 1 + 2)
	Element 2	4	1,3	80 + 800 (component 1 + 2)

Result aggregation object 1 = $\frac{15500*1,02+3000*1,0+1300*1,7}{15500+3000+1300}$ = 1,06.

Result aggregation object 2 = $\frac{7100*1,0+880*1,3}{7100+880}$ = 1,03.

12. The object result score is converted by *Table 19* condition determination.

    Result object 1 aggregation = 1,06, object 1 condition score = 3

    Result object 2 aggregation = 1,03, object 2 condition score = 2

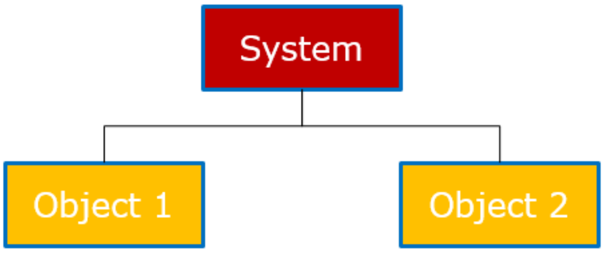
13. The final result is the aggregated condition score of the objects. Object 1 has condition score 3. Object 2 has condition score 2.

1	2	3	4	5	6
Excellent	Good	Reasonable	Moderate	Bad	Very bad

OCA aggregation steps to system level

The aggregation from object to system level is done by adding two extra steps to the aggregation steps from component to object level:

13. The system result score is the aggregation from object to system level and based on the object decomposition, object condition scores, object material cost and correction factors. The decomposition shows the system and its objects. The table provides the condition score, correction factor and material cost of the objects.



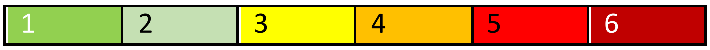
		Condition score	Correction factor	Material cost (€)
System	Object 1	3	1,1	15500 + 3000 + 1300 (element 1 + 2 + 3)
	Object 2	2	1,02	7100 + 880 (element 1 + 2)

System aggregation result score = $\frac{19800*1,1+7980*1,02}{19800+7980}$ = 1,08.

14. The system condition score is converted by *Table 19* condition determination.

    System aggregation result score = 1,08, system condition score = 3

15. The final result of the system is condition score 3



Appendix VII. Data for aggregation

Object A – Wooden bridge (Municipality)

Object A is a fixed, wooden bridge that was built in 1976 and provides passage for mixed traffic (*Figure 36*). The bridge is the link between a residential system and a school. There is a mix traffic using this bridge which are pedestrians, bicycles, cars and small trucks.

Figure 36 - Cast study A: Wooden Bridge

Table 22 shows the decomposition of object A divided in elements and components. This decomposition is made by the asset owner, asset manager or inspector.

Table 22 - Decomposition of Wooden Bridge

Object	Element	Component
Wooden Bridge	Anti-vandalism provision	Fence
	Main supporting structure	Longitudinal beam
		Pole
		Drive deck
	Handrail construction	Handrail
	Wear layer	Wear layer (general)
	Support	Support (general)

Table 23 shows defects of the wooden bridge based on inspection. Based on the seriousness, size and intensity, a condition score from 1-6 is found for each defect conform the NEN2767. A condition

score 1 is excellent and condition score 6 is very bad.

Table 23 - Defects of Wooden Bridge Components

Component	Defect	Seriousness	Size	Intensity	Condition Score
Longitudinal beam	Rotten wood	Important	Local	Advanced	2
Pole	Rotten wood	Important	General	End	6
Handrail	Rotten wood	Important	Local	Advanced	2

Object B – Concrete bridge (Province)

The bridge over the Roer in the N293 in Roerdalen (St. Odiliënberg) consists of three parts which can be seen in *Figure 37*: a concrete arch bridge, rebuilt in 1948 (originally built in 1908), and on both sides of the concrete arch bridge free bicycle bridges, built in 1976.

The reinforced concrete arch bridge with three fields is a statically determined structure. Two continuous very thin and weak reinforced side walls have been placed on the arches and on the intermediate support points to support the floor. The arches on which the deck rests are supported by two abutments and two intermediate pillars. These abutments and intermediate pillars have a foundation of steel. The entire superstructure's construction is composed of reinforced concrete. This is one of the first reinforced concrete bridges constructed in the Netherlands.

The concrete bicycle bridges on both sides of the arch bridge are statically determined on four support points. The main span involves a suspension beam (Gerber beam) and a tooth construction. The road deck consists of prefabricated pre-stressed beams and rests on two abutments and two intermediate pillars founded on poles. The supports are oval rubber blocks.

Figure 37 - Case study B: Concrete Bridge

Table 24 shows the decomposition of object B. This decomposition is made by the asset owner, asset manager or inspector.

Table 24 - Decomposition of Concrete Bridge

Object	Element	Component
Concrete Bridge	Guide construction	Guiderail
	Main supporting structure	Main supporting structure (General)
		Beam
		Arch
		Drive deck
	Rainwater drainage	Drain
		Pond
	Handrail construction	Handrail
	Bearing	Bearing (General)
	Support	Pillar
		Abutment
		Support beam
		Foundation block
	Slope	Slope (General)
		Revetment
	Expansion joint	Sealing strip
		Expansion joint (General)

Table 25 shows the defects of the concrete bridge. This table is originating from inspection. Based on seriousness, size and intensity a condition score from 1-6 is found for each defect conform NEN2767. Condition score 1 is excellent and condition score 6 is very bad.

Table 25 - Defects of Concrete Bridge Components

Component	Defect	Seriousness	Size	Intensity	Condition Score
Arch	Reinforcement corrosion	Important	Incidental	Advanced	1
	Crumble	Important	Incidental	Advanced	1
	Crack, constructive	Important	Incidental	Advanced	1
	Graffiti	Low	Local	End	1
Main supporting structure (General)	Wear, mechanical	Serious	Considerable	Advanced	3
Drive deck	Degradation, critical	Important	Incidental	Advanced	1

Cost explanation

The aggregation criteria selected in chapter 3 are translated to costs. To ensure a uniform approach, a standardized table presented in Appendix XI. has been developed based on:

1. A cost database of an engineering firm (The cost database has been developed over years by executing projects and experience of cost experts);
2. Cobouw GWWkosten (Cobouw GWWkosten has been collecting cost data for soil, road and hydraulic engineering for 60 years);
3. A cost expert or actuary.

The cost is built up as follows unless stated otherwise:

1. Material purchase price, wages and rental equipment;
2. Excluding profit, risk, general costs and implementation costs;
3. Exclusive of engineering and supervision costs;
4. Excluding special equipment (diving team, platform etc.), environmental measures, traffic measures, permits;
5. Exclusive of VAT.

Databases of the engineering firm and Cobouw are used to determine the costs for chosen measures and material cost. If cost is lacking, it will be calculated, or estimated with the expertise of a cost expert.

Case study A: Wooden bridge

Defects wooden bridge

The effects of defects will be translated into the following criteria: material cost, defect cost, safety, environment and aesthetics. Cost will be determined by analyses of a cost database and if necessary by a cost expert. The dimensions of the bridge are 14 meters long and 4 meters wide.

Material cost

First, costs of new materials are calculated.

Table 26 - Material cost determined

Component	Quantity	Quantity cost	Material cost (in euro)
Fence	1 (4,5 m)	1500/piece	1.500
Longitudinal beam	5 m3 (14 *0.2*0.35 *5)	1600/m3	8.000
Pole	40 m (4*10)	100/m	4.000
Drive deck	3.2 m3 (14 * 4 * 0.05)	1600/m3	5.120
Handrail	28 m (14 * 2)	70/m	2.000
Wear layer (general)	64 m2 (14 * 4)	50/m2	3.200

Support (general)	2 (Abutment) 5 (Concrete Poles) 8 (Connection bar, 4*0.2*0.3=0.24 m3)	1500/piece 400/piece 1600/m3	5.384

Defect cost

The defect cost is the cost to solve or mitigate a defect by a measure. If a component has no defect it won't have a defect cost.

Table 27 - Defect cost determined

Component	Defect	Measure	Quantity	Quantity cost (in euro)	Defect cost (in euro)
Longitudinal beam	Rotten Wood	Repair/replace beam	5.0 m3 64 m2 (Labor + material)	1600/m3 100/m2	14.400
Pole	Rotten Wood	Replace pole	40 m (4*10)	150/m	6.000
Handrail	Rotten Wood	Repair handrail	14 m (1 piece)	120/m	1.680

Safety Costs

Safety issues are a priority. Therefore, defects of components that cause safety concerns are determined and measures are taken to solve or mitigate negative effects.

Table 28 - Safety issues and measures determined

Component	Defect	Safety effect	Measure	Cost (in euro)
Longitudinal beam	Rotten Wood	Beam is in good condition (condition score 2). No safety issue currently.	Monitor (Inspect (Schouwen) 2x a year 8 hours)/ further future technical investigation	4.300 (1.800+2.500)
Pole	Rotten Wood	Pole is in critical condition with condition score 6. Great chance of bridge collapse is present. Harm to users.	Immediate replacement is necessary	6.000
Handrail	Rotten Wood	Loose handrail may cause falling danger for users.	Check/attach handrail	120

Environmental costs

As mentioned in Appendix IV, the bridge is the only access point between a residential system and the school. Any serious defects can cause major problems for the accessibility of the system. The school provides special education for hearing-impaired children, children with language development disorders and some children with autism. A safe environment is necessary for the optimal development of children. Accessibility, the quality of the system and any potential nuisance will be considered.

Table 29 - Environment issues and measures determined

Component	Defect	Environment effect	Measure	Cost (in euro)
Longitudinal beam	Rotten Wood	Beam isn't directly seen by users. No direct environmental effect since condition score is 2, but may cause accessibility, quality and nuisance problems in the near future if rotten parts develop rapidly.	Monitor (Inspect (Schouwen) 2x a year 8 hours)/	1.800
Pole	Rotten Wood	The critical condition of the pole can cut accessibility and cause major nuisance for the system. The school, parents, children, residents and service providers will be negatively influenced.	Investigate the critical condition of the pole. If criticality is proven, prioritize replacement during the weekend to minimize nuisance during schooldays.	8.500 (2.500+6.000)
Handrail	Rotten Wood	Users directly see and use the handrail. Rotten wood can give a negative impression and implies an unsafe system quality and may cause a hindrance for users with special needs.	Replace or treat the system of rotten wood.	1.800 (1.680 + 120)

Aesthetics Costs

The aesthetics of objects are representative for the system and should be maintained at agreeable levels. Well maintained objects are more beautiful, but also have an appearance of being safer. The object may be safer in the sense of preventing slips and falls due to moss and algae growth. By conducting regular maintenance, the life of sensitive parts is extended by preventing fungi that cause wood rot and preventing moss and algae that cause fluid retention. After cleaning, invisible and / or hidden defects are visible earlier and targeted maintenance can take place. Object aesthetics and its influence on company image/reputation will also be considered.

Table 30 - Aesthetic issues and measures determined

Component	Defect	Aesthetics	Measure	Cost (in euro)
Longitudinal beam	Rotten Wood	No direct influence on aesthetics. Defect can't be seen directly by users. The owner of the object can see that fungi has caused wood rot. This may spread to visible parts and provide unsafe image.	Regular maintenance (life extending, cleaning)	350
Pole	Rotten Wood	Unsafe (reached end of life) and unslightly appearance of object for users. Company may generate danger for users by neglecting safety. Damaging image/ reputation of company by irresponsible actions.	Keep stakeholders up to date. Calculate/prove remaining capacity. Replace if not up to standards.	1.900 (400 + - 1.500)
Handrail	Rotten Wood	A piece of handrail wood is broken leaving a hole surrounded by fungi. This defect is directly seen by users and may provide unpleasant and unsafe circumstances.	Solve defect by repair or replacement.	1.800 (1.680 + 120)

Defects concrete bridge

The effects of defects will be translated into the following criteria: material cost, defect cost, safety, environment and aesthetics. The cost for all criteria except material cost includes materials, labor, machine and disposal cost. Costs will be determined by analyses of a cost database and if necessary by a cost expert or actuary. The dimensions of the bridge are 76 meters long and 18 meters wide.

Material costs

First, the costs of new materials are calculated.

Table 31 - Material cost determined

Component	Quantity	Quantity cost	Material cost (in euro)
Guiderail	2*76 m	50/m	7.600
Main supporting structure (Asphalt, General)	76 m	15/m	1.140
Beam	532 m3 (76*10*0.7)	100/m3	53.200
Arch	1125 m3 (3*3*25*10*0.5)	100/m3	112.500
Drive deck (concrete cross bars)	364.8 m3 (2*76*3*0.8)	100/m3	36.480
Drain	6	150/piece	900

Pond	4	140/piece	640
Handrail	2*76 m	200/m	30.400
Bearing (General)	1.2 m2 (24*0.25*0.2)	3685/m2	4.422
Pillar	6 m3 (4*(0.8*0.8*0.25π) *3)	120/m3	720
Abutment	2	28225/piece	56.450
Support beam	3 m3 (4*3*0.5*0.5)	120/m3	360
Foundation block	9 m3 (2*3*3*0.5)	120/m3	1.080
Slope (General)	128 m3 (2*8*4*4*0.5)	10/m3	1.280
Revetment	64 m3 (2*8*4)	10/m2	640
Sealing strip	1 m2 (8*0.25*0.5)	50/m2	50
Expansion joint (General)	32 m (4*8)	527.5/m	16.880

Defect costs

The defect cost is the cost to solve or mitigate a defect by a measure. If a component has no defect it won't have defect cost.

Table 32 - Defect cost determined

Component	Defect	Measure	Quantity	Quantity cost (in euro)	Defect cost (in euro)
Main supporting structure (Asphalt, General)	Wear, mechanical	Repair Asphalt	380 m2	55/m2	20.900
Arch	1. Reinforcement Corrosion 2. Crumble 3. Crack, Constructive 4. Graffiti	0. Technical investigation 1. Cathodic protection 2 & 3 Concrete repair 4. Cleaning surface	1,2 & 3 = 14 m2 4 = 41 m2	0. 2.500/piece 1. 100/m2 2. 250/m2 3. 250/m2 4. 25/m2	11.925 (2.500+1.400+3.500+3.500+1.025)
Drive deck (concrete cross bars)	Degradation, critical	Repair Concrete + Cathodic protection	14 m2	250/m2 100/m2	4.900 (3.500+1.400)

Safety costs

Safety issues are a priority. Therefore, defects of components that cause safety concerns are determined and measures are taken to solve or mitigate effects.

Table 33 - Safety issues and measures determined

Component	Defect	Safety effect	Measure	Cost (in euro)
Main supporting structure (General)	Wear, mechanical	Cracks or pits in asphalt can cause unsafe provincial road conditions. This can result in car accidents	Repair asphalt	20.900
Arch	1. Reinforcement Corrosion 2. Crumble 3. Crack, Constructive 4. Graffiti	1,2 & 3. Corroding reinforcement and damage to concrete can crumble, crack and break. Causing stability issues and less bear capacity. 2. 4. No effect	1. Apply cathodic protection 2. Repair concrete 3. Technical investigation, monitor crack and repair if required 4. None	12.500
Drive deck	Degradation, critical	Damage to concrete due to chlorides or carbonation causing corrosion of reinforcement. Leads to less capacity endangering structural safety	Further technical investigation (chlorides or carbonation content), cathodic protection and repair concrete.	7.400

Environment costs

The bridge is part of a provincial highway providing possibilities for mixed traffic. The road connects Roermond with the German border near Posterholt and the route continues to Heinsberg. The road is 11 kilometers long. Any serious defect can cut off accessibility in the system and create a nuisance.

The consequences of decisions made during projects that affect the environment are becoming more important to consider to avoid negative outcomes. Leaving future generations with equal or better environment is essential. Accessibility, quality living system and nuisance will be considered. Therefore, defects of components causing harm to the environment will be determined.

Table 34 - Environment issues and measures determined

Component	Defect	Environment effect	Measure	Cost (in euro)
Main supporting structure (General)	Wear, mechanical	Further deterioration of asphalt can lead to unsafe road conditions/closures. Limiting accessibility and causing a nuisance for the whole system.	Repair asphalt	20.900
Arch	1. Reinforcement Corrosion 2. Crumble 3. Crack, Constructive 4. Graffiti	Rapidly developing corrosion or cracks will cause serious accessibility and nuisance issues. Closure of the bridge may result if structural safety is in danger.	Monitor reinforcement, crumble and cracks.	4.800
Drive deck	Degradation, critical	No direct effects, but serious damage to the concrete due to chlorides or carbonation may result in bridge closure	Further technical inspection	2.500

Aesthetics costs

The aesthetics of objects are representative for the system and should be maintained at agreeable levels. Well maintained objects are more beautiful, but also have an appearance of being safer. The object may be safer in the sense of preventing slips and falls due to moss and algae growth. By conducting regular maintenance, the life of sensitive parts is extended by preventing fungi that cause wood rot and preventing moss and algae that cause fluid retention. After cleaning, invisible and / or hidden defects are visible earlier and targeted maintenance can take place. Object aesthetics and its influence on company image/reputation will also be considered.

Table 35 - Aesthetic issues and measures determined

Component	Defect	Aesthetics	Measure	Cost (in euro)
Main supporting structure (General)	Wear, mechanical	Lots of cracks are visible providing unsafe and unpleasant 'feelings'.	Repair asphalt	20.900
Arch	1. Reinforcement Corrosion 2. Crumble 3. Crack, Constructive 4. Graffiti	Not visible to users	X	X

Drive deck	Degradation, critical	Not visible to users	X	X

Summation of costs for aggregation criteria

The costs for both bridges are summarized. This is calculated by adding up all costs of each criteria.

Total of aggregated of summation of costs wooden bridge

Component	Sum Cost
Fence	1.500
Longitudinal beam	28.850
Pole	26.400
Drive deck	5.120
Handrail	7.400
Wear layer (general)	3.200
Support (general)	5.300
Total cost	77.770

Total of aggregated of summation of cost concrete bridge

Component	Sum. Cost
Guiderail	7.600
Main supporting structure (Asphalt, General)	84.740
Beam	53.200
Arch	141.725
Drive deck (concrete cross bars)	51.280
Drain	900
Pond	640
Handrail	30.400
Bearing (General)	4.422
Pillar	720
Abutment	56.450
Support beam	360
Foundation block	1.080
Slope (General)	1.280
Revetment	640
Sealing strip	50
Expansion joint (General)	16.880
Total cost	452.367

Appendix VIII. Uniform tables

The goal of the uniform tables is to aggregate in a uniform, objective and reproducible way. The measures are determined by looking at defects and asking the following questions:

- Which measures can solve this defect?
- How are the defects solved in practice?
- How applicable is the chosen measure in practice?
- Does the measure solve or mitigate the defect?

Cost originate from:

- Cost database of engineering.
- Cobouw GWWKosten.
- Cost expert.

Uniform table for material cost

This chapter shows the result of the uniform table designed for the 31 bridges.

Table 36 - Uniform table for material costs

Component	Cost (in euro)	Unit
Wooden Bridge		
Component	Cost (in Euro)	Unit
Fence	1500	piece
Longitudinal beam	1600	m3
	4600	ton
Pole	100	m
Drive deck	1600	m3
Wire	15	m
Abutment wing wall	240	m2
Sheet pile	100	m
Handrail	70	m
Wear layer, general	50	m2
Revetment	30	m2
Support, general	100	m
	100	m3
Foundation, general	1500	piece
	400	piece
	1600	m3
Diagonal (lattice girder)	200	piece
Drive deck iron	400	m
Concrete Bridge		
Guiderail	50	m

Main supporting structure, general	10	m2
	100	m3
Rainwater drainage	50	m
Beam	100	m3
Arch	100	m3
Drive deck	100	m3
Curb, general	20	m2
Curb strip	50	m2
Support, general	350	piece
Wear layer, general	75	m2
Sheet pile	100	m
Sheet pile	930	ton
Abutment wing wall	30	m2
Purlin	115	m
Drain	150	piece
Grid	20	piece
Pond	140	piece
Panel	265	m
Handrail	200	m
Bearing, general	3685	m2
Longitudinal beam	100	m3
Pillar	120	m3
Abutment	28225	piece
Support beam	120	m3
Foundation block	120	m3
Slope, general	15	m2
Revetment	15	m2
Sealing strip	50	m2
Expansion joint, general	527.5	m

Uniform table for measures

This chapter shows the result of the uniform table designed for the 31 bridges.

Table 37 - Uniform table for measure costs

Component	Defect	Measure	Cost (in euro)	Unit
Standard Measures				
[redacted]		Technical investigation	2500	1
		Monitoring	1800	1
		Inspect	100	1
		Maintenance inspection	250	1
		Inform stakeholders	400	1
		Regular maintenance (small object cleaning)	350	1
		Regular maintenance (large object cleaning)	600	1
Wooden Bridge				
Longitudinal beam	Rotten wood	Replace longitudinal beam	1600	m3
			100	m2
Pole		Replace pole	150	m
Handrail		Replace handrail	120	m
	Attachment, missing	Recover/connect parts	50	piece
	Attachment, defect	Recover/connect parts	50	piece
	Function, reduced	Replace handrail	120	m
	Crack, non-structural	Inspect	100	1
	Cracking	Recover/connect parts	50	piece
Drive deck	Attachment, incorrect	Recover/connect parts	50	piece
	Attachment, defect	Recover/connect parts	50	piece
	Rotten Wood	Replace bicycle/pedestrian deck	170	m2
		Replace car deck	350	m2
	Cracking	Replace bicycle/pedestrian deck	170	m2
		Replace car deck	350	m2
Drive deck iron	Corrosion, uniform	Inspect	100	1

Support, general	Attachment, missing	Recover/connect parts	50	piece
	Rotten wood	Replace support, general	400	piece
Abutment wing wall	Rotten wood	Replace abutment wing wall	240	m2
Wear layer, general	Wear, mechanical	Replace wear layer, general	75	m2
Diagonal (lattice girder)	Connection, defect	Recover/connect parts	50	piece
Concrete Bridge				
Main supporting structure, general	Wear, mechanical	Repair asphalt	55	m2
	Rut	Repair asphalt	55	m2
	Crack, non-structural	Inspect	100	1
Arch	Reinforcement corrosion	Apply cathodic protection	100	m2
	Crumble	Repair concrete	250	m2
	Crack, structural	Repair concrete	250	m2
	Graffity	Clean	25	m2
Drive deck	Degradation, critical	Repair concrete + Apply cathodic protection	350	m2
	Crack, non-structural	Inspect	100	1
Expansion joint, general	Corrosion, uniform	Inspect	100	1
Handrail	Protective layer, defect	Conserve protective layer	50	m
	Gap	Recover/connect parts	50	piece
	Attachment, defect	Recover/connect parts	50	piece
	Corrosion, uniform	Conserve handrail	40	m
Wear layer, general	Fray	Correct asphalt layer	25	m2
Rainwater drainage	Corrosion, uniform	Inspect drainage flow	100	1
Support, general	Crack, structural	Repair concrete	250	m2
	Erosion	Monitor	1800	1
Revetment	Part, missing	Recover revetment	50	m2
	Leaching	Recover revetment	50	m2
	Crack, non-structural	Inspect	100	1
Beam	Part, missing	Recover/connect parts	50	piece
	Graffity	Clean	25	m2
Abutment	Graffity	Clean	25	m2
	Crack, non-structural	Inspect	100	1
Pillar	Graffity	Clean	25	m2
Sheet pile	Rotten wood	Replace sheet pile	140	m2

Appendix IX. Selection of bridges

The selection of the bridges is based on several criteria. First, the selection is based on the availability and completeness of the basic and inspection data. Secondly, a decent number of defects and variety in condition scores is present. Finally, at least medium sized bridges were chosen that transported a mix of traffic types. An overview of all bridges is given in *Table 38*.

Table 38 - Bridge selection

Object code	Object name	Object number	Length	Width	Defect
KW_0011	SB901	1	17,6	4,2	1
KW_0055	PB01	2	8,0	2,3	3
KW_0056	PB02	3	8,5	1,1	3
KW_0010	SB801	4	9,5	1,5	5
KW_0223	SmB02	5	9,0	3,2	2
KW_0020	TB01	6	13,2	2,4	1
KW_0025	BB01	7	15,0	1,0	3
KW_0087	SB05	8	13,0	2,9	2
KW_0101	SB610	9	14,5	4,0	3
KW_0089	PB01	10	16,2	6,8	3
KW_0105	SB613	11	14,1	2,6	2
KW_0130	SmB01	12	8,0	1,5	2
KW_0090	SB402	13	15,3	2,6	1
KW_0091	SB404	14	17,2	1,6	1
KW_0094	SB406	15	18,2	1,4	2
KW_0102	SB611	16	14,0	2,1	3
KW_0224	SmB03	17	80,0	1,5	2
KW_0588	SB624	18	21,2	3,3	5
KW_0608	WB01	19	21,0	4,3	5
KW_0611	WhB15	20	12,6	3,4	1
KW_0585	OkB01	21	19,2	5,0	3
KW_0132	SbB08	22	16,0	5,0	2
KW_0026	BB02	23	8,0	8,8	2
KW_0079	SB01	24	13,0	10,8	3
KW_0111	SB620	25	6,0	8,0	1
KW_0314	SB627	26	21,0	13,2	3
K04-293	-	27	76,3	17,8	6
K02-570	-	28	8,0	22,4	4
K03-293	-	29	10,5	17,5	3
K07-297	-	30	46,0	20,0	2
K26-276	-	31	11,6	18,3	4

Appendix XI. Inspection form

SWECO

Kunstwerkcode

INSPECTIEDATUM	INSPECTIETEAM	FOTO'S

PASPOORT

OBJECTCODE	OBJECTNAAM	STRAAT
VAKDISCIPLINE Kunstwerken	BEHEEROBJECT Brug (vast)	KUNSTWERKTYPE
FUNCTIEGEBRUIK	MATERIAAL	BOUWJAAR
EIGENAAR/BEHEERDER	LENGTE / BREEDTE Le= Br=	LEUNINGHOOGTE/LENGTE Ho= Le=

BEPALINGEN VOOR CONDITIESCORE (CS)

ERNST (E)	INTENSITEIT (I)	OMVANG (O)	
GERING (G)	BEGIN (B)	<2%	INCIDENTEEL (1)
SERIEUS (S)	GEVORDERD (G)	2-10%	PLAATSELIJK (2)
ERNSTIG (E)	EIND (E)	10-30%	REGELMATIG (3)
		30-70%	AANZIENLIJK (4)
		>70%	ALGEMEEN (5)

DECOMPOSITIE

NR	ELEMENT	BOUWDEEL	MATERIAAL	AANTAL	NR	ELEMENT	BOUWDEEL	MATERIAAL	AANTAL
1					9				
2					10				
3					11				
4					12				
5					13				
6					14				
7					15				
8					16				

GEBREKEN EN CONDITIES

NR	GEBREK	E	I	O	HERSTELADVIES