# CME 1210
## INFRASTRUCTURE ASSET MANAGEMENT
## STUDY GUIDE AND READER

CONSTRUCTION MANAGEMENT AND ENGINEERING

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# INSTRUCTORS AND CONTACT

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# STUDY LOAD

7 ECTS

# EDUCATION PERIOD

Q2
Starting date: 20 November 2017
No lectures in week 2.1 because of CME International Business Tour

# COURSE LANGUAGE

English

# CONTENTS

# 1 COURSE CONTENTS AND CONTEXT

## 1.1 Course Contents

Infrastructure Asset Management deals with:
- Analysis of problems and projects in the context of civil infrastructures;
- Orientation on models, methods and techniques for decision making;
- Proper application of justified methods and techniques;
- Critical review of one's own work and somebody else's work.

The course has two lines of content:
- The first is to learn to integrate newly acquired and previously acquired methods, techniques, aspects and tools in multidisciplinary asset management problems;
- The second is to learn to critically look at the problems from various viewpoints, including the viewpoint of an assessor/auditor.

This course will build on the different backgrounds of the students, coming from various faculties, universities and/or countries.

The course has roughly three blocks:
1. Theory on asset management, performance management and the building of a toolkit of models, methods and techniques;
2. Application and integration of proper methods/techniques from the toolkit in a case study;
3. Assessment/audit of the result of (somebody else's) case study.

The first block is aimed at learning and acquiring a toolkit of models, methods and techniques for analysing and solving a wide range of problems in asset management. In this phase the setting of the case study for the group assignment is also explained. The different approaches for tackling multidisciplinary asset management problems are dealt with within the framework of *Asset Management*, see Asset Management – an anatomy (The Institute Of Asset Management, 2015) and The Asset Management Landscape (GFMAM, 2014). Both documents are freely available from the Internet. *The Asset Management – an anatomy* is compulsory reading and will be used in class.

For an overview of asset management *Physical Asset Management* (Hastings, 2015) by Hastings is used. Links to more in depth literature will be given during the lectures.

In the second block, you will conduct a case study in small groups, and solve the given problem by finding the best matching method or technique and apply this, plus appropriate other methods. The small groups consist of students with different backgrounds that will apply their own knowledge, skills, competencies on this real-life case; this will result in a crossover and integration of knowledge.

In order to view the problem (case) from a completely different viewpoint, the third block is about assessing or auditing. In this block, each of you will individually audit the results of a case study. Of course, this will not be the report from your own group.

## 1.2 CME1210 Compared to CME1200

CME1210, Infrastructure Asset Management has a focus on the harder, more quantitative approach for dealing with multidisciplinary asset management problems, whereas CME1200 Collaborative Design & Engineering focuses on the soft factors that are key for successfully dealing with complex problems in large groups. In CME1210 students will work together in small groups complemented with an individual assignment.

Table 1 Infrastructure Asset Management compared to Collaborative Design and Engineering

| Infrastructure Asset Management | Collaborative Design and Engineering |
|---|---|
| Focus on hard factors | Focus on soft factors |
| Small groups (5-6 max) | Large groups (~ 25-30 max) |
| Analysis of methods/techniques | Complex problem analysis |
| Theory, application and audit report | Two reports: analysis and design |
| Peer review (of application report) | Peer pressure – groups dynamics |
| Apply own RQ to given case | Apply RQ to a given case |
| Audit of each other's report | Self-reflection (Kolb) |

## 1.3 Context of the Course

The course Infrastructure Asset Management (CME1210) is part of the MSc Construction Management and Engineering. The content of the CME programme comprises all aspects of the construction process, including the definition, appraisal, design and delivery of the projects, as well as the lifetime management of objects. The programme addresses the interests of all stakeholders involved, as well as those of the construction business in its broadest sense. For this reason, the research underlying the CME programme has generated an interdisciplinary programme focusing on the integration of technology and management in order to produce innovative solutions to societal needs in the field of construction engineering. The design-oriented approach, the strong connection between scientific research and construction engineering practice, and the emphasis on disciplinary integration are distinctive features of this Master's programme.
The general mission of CME is to improve the performance of the construction industry and to deliver solutions to societal problems. More specifically, the goals of CME are:

- To produce good engineers with a wide range of competencies: The competencies (knowledge, skills and attitude) ensure that the students possess current knowledge, that they are able to use state-of-the-art methods, techniques and tools, and that they will develop a professional attitude that will allow them to perform at the highest level.
- To educate students as critical professionals who are able to serve as and collaborate with professionals in various national and international settings.
- To provide a stimulating and supportive environment in which students can learn the competencies that will be expected of the managers of tomorrow.
- To realise regular involvement with the national and international construction industry at all levels.
- To offer education in which students are able to integrate technical and management issues.

The compulsory courses of the CME master are divided into three main topics: 1) project management in general, 2) aspects of construction projects, 3) other courses.

## Project Management in General

- Project Management (SPM8000). This course is designed to provide the student with scholarly knowledge in the practice of managing construction projects, mainly major construction projects, in order to prepare the student to move into managerial roles.
- Dynamic Control of Projects (CME2200). This course gives a completely different view on standard project management. The worlds in and around a building or structure changes faster than the building or structure. This requires new methods of control in which the built environment is subject to change during its lifetime.

## Aspects of Constructions Projects

CME students will need insights, concepts and skills to understand the nature of interaction between actors regarding the initiation and development of and decision-making on projects under uncertain and dynamic conditions.

- Process Management (SPM8002). This course provides the student with understanding of and how to adequately deal with above characteristics, in addition to project management.
- Collaborative Design and Engineering (CME1200). In this course the students gain a better understanding of combining interests of various actors and collaboration within a design team by carrying out a design project in collaboration.
- Financial Engineering (CME2300) deals with the finance issues related to the implementation of civil engineering projects.
- Legal and Governance (AR8002). This course covers the legal aspects of construction projects. After this course the students will be able to communicate with legal specialists and to anticipate legal issues while managing the others aspects of their project.
- Intercultural Relations and Project Management (EPA1433). The course teaches the student to understand how cultural differences between people from different regions in the world impact on their organisational and problem-solving behaviour.

## Other Courses

- Methodology for Scientific Research (CIE4030). After this course the student will be able to design a research project, apply the proper statistical testing theory, to critically examine the literature on his field of study and to apply the proper research methodology.
- Philosophy, Technology Assessment and Ethics for CT (WMO312CIE). This course provides the student with more knowledge on philosophy and ethics applied to the world of building and construction.

# 2 STUDY GOALS

After this course, for a given multidisciplinary asset management problem, you will be able to:
- Specify, choose, apply and evaluate the most appropriate mix of methods, techniques and tools to analyse the problem at hand for making decisions;
- Look at the problem from various viewpoints and apply these viewpoints in your decision making;
- Deal with an overload of information, that is partly incomplete and/or inaccurate, and still deliver clear results, as is expected from a good engineer.

The overarching goal of the lectures is to give you an overview of asset management and its principles. Specific focus will be on goal setting and alignment of objectives. That will be the context in which you will apply one or more asset management methods or techniques. The lectures about the methods or techniques are meant to show you what a certain method is meant for and what the possibilities and limitations are. In a small group, you will apply a method in a (given) case and individually you will critically scrutinise somebody else's group report. This is paramount for your future as (construction, asset) managers, when you will have to be able to (quickly) assess reports from your staff and consultants. The lectures on the methods or techniques are a stepping-stone if you want to specialise further in this field. Links to more in depth literature will be given.

## 2.1 Learning Objectives

More specifically the learning objectives are, that you will be able to:
1. Understand asset management principles;
2. Have a holistic view on solving asset management related problems;
3. Select appropriate methods or techniques from a large array of methods/techniques;
4. Underpin the choice of methods/techniques for solving a problem;
5. Critically scrutinise one's own work or somebody else's work;
6. Work with incomplete data, requirements and scenarios;
7. Work in small teams with people of various backgrounds and cultures.

## 2.2 Academic Skills

The course also focuses on developing generic academic skills. One lecture will address methodology, critical thinking and scientific writing. In that lecture conditions for assessing the proper application of methods or techniques will be discussed.
1. Critical thinking;
2. Problem solving;
3. Writing reports;
4. Judgemental skills;
5. Reasoning.

# 3 COURSE DESIGN

## Course Organisation

Rob Schoenmaker and Jules Verlaan coordinate the course CME1210. It is important to notice that this is a Master's course and will build upon the knowledge the students already have, not only from the Bachelor phase but also from the other cornerstones in de CME master.

## Study Load

The course is 7 ECTS over a period of 10 weeks. The deadline for the individual assignment is several weeks into period 3, check Brightspace for the exact date and time. This results in an average study load of about 18 hours per week – excluding holidays.

## Education Method

The course is a project course with one group assignment and one individual assignment. There are two lectures every week in week 2.2 to 2.8 - not in week 2.1 because of the CME International Business Tour. There are opportunities for consultation and guidance (upon request) in the last two weeks of period 2. There is no separate examination of this course. The assessment is done based on the group and individual results. For more details, see paragraph 5.

## Course Timeline

During week 2.2 to 2.5, the first part of the course, the emphasis of the lectures is on knowledge transfer (introduction of the assignments, theory, methods and the case). During week 2.6 to 2.10, the second part of the course, the emphasis is on guiding you through the individual assignment.

There are four types of lectures: theory, workshops and presentations, and consultation.

1. *Theory*
   The (theoretical) lectures are preceded by a reading assignment. The lectures on the methods or techniques will be activity based, using worked examples to try and test the theory. The lectures on asset management and performance management will use in-class case study assignments to practice the theory.
2. *Workshops*
   One large case study will be dealt with. You will have to apply your new asset management overview skills to give recommendations on improving asset management an organisation.
3. *Presentations*
   The groups will present their progress on their case study. All groups have to prepare for this presentation; because of the available time the lecturers will select only a limited number for presentation and discussion.
4. *Consultation*
   The consultation meetings are on appointment. The goal is to give you guidance during the last assessment: the audit assignment.

## 3.1 The Course and the Assignments

*Group Assignment:*
Early on in the course you will be assigned to a small group. Each group will be as diverse as possible. Ideally each group consists of an international student; a student with a Bachelor in Architecture; a student with a Bachelor in TPM and a student with a Bachelor in Civil Engineering.
Each group is given a problem description within a certain case. Each group will select a suitable method or technique for this problem in the case study. In consultation with the lecturers a group can apply additional methods of their own choosing.

*Individual Assignment:*
Before the end of 2017 each of you will be assigned to assess/audit the paper of a group (case study) that you have not been part of.

## 3.2 Lectures and Deadlines

The lectures for this course will be on Monday and Wednesday (13:45 – 15:30).
For the exact time and location check: http://huidigeroosters.tudelft.nl

*In order to prepare for the first lecture, read the introductory literature that is mentioned on Brightspace.*

Table 2: Course Outline and Overview of Assignments (I=Individual, G=Group)

| Lectures | | | Aspects (tentative) | | Assignment (I or G) |
|---|---|---|---|---|---|
| 2.1 | Monday 13 Nov '17 | | No lectures – CME Study Tour | X | Read intro literature, See Brightspace |
| | Wednesday 15 Nov '17 | | No lectures – CME Study Tour | X | |
| 2.2 | Monday 20 Nov '17 | 1 | Introduction to the course<br>Intro to assignments<br>AM Overview | RS | Read literature<br>Formation of groups<br>Start case study (G) |
| | Wednesday 22 Nov '17 | 2 | Reliability Centred Maintenance - Failure Mode, Effect and Criticality Analysis | MvdB | Read literature |
| 2.3 | Monday 27 Nov '17 | 3 | Case Study Assignment Explanation | RS | Read literature |
| | Wednesday 29 Nov '17 | 4 | Reliability and Availability of Components | MvdB | Read literature |
| 2.4 | Monday 4 Dec '17 | 5 | Reliability and Availability of Systems | MvdB | Read literature |
| | Wednesday 6 Dec '17 | 6 | Life Cycle Costing | MvdB | Read literature |
| 2.5 | Monday 11 Dec '17 | 7 | Methodology – academic skills | RS | Read literature |
| | Wednesday 13 Dec '17 | 8 | Progress Case Study<br>Problem – Goal – Research Question | RS | Presentation and Q&A |
| 2.6 | Monday 18 Dec '17 | 9 | Performance Management – Alignment of Objectives - Line of Sight | RS | Read literature |
| | Wednesday 20 Dec '17 | 10 | Asset Management Overview – Workshop | RS | Read literature |
| Christmas Break | | | | | |
| 2.7 | Monday 8 Jan '18 | 11 | Progress Case Study<br>Conclusion - Recommendations | RS | Presentation and Q&A |
| | Wednesday 10 Jan '18 | 12 | Auditing 1 - Theory | RS | Reader<br>Start Audit Paper (I) |
| 2.8 | Monday 15 Jan '18 | 13 | Auditing 2 - Workshop | RS | Define objectives/assertions |
| | Wednesday 17 Jan '18 | 14 | Consultation by appointment | RS | |
| Friday, 12 Jan '18 | | Hand-in description of case study | | | |
| 2.9<br>2.10 | Mo/Wed | | Consultation by appointment | RS | |
| Friday, 16 Feb '18 | | Hand-in audit report | | | |

RS = Rob Schoenmaker; MvdB = Martine van den Boomen

## 3.3 Lectures

The following descriptions of the lectures are for information purposes only.
The content of each lecture may be subject to change.

> All compulsory literature is available via library.tudelft.nl (on campus) or freely downloadable from the Internet.

| Week 2.2<br>Introduction to the Course and the Assignments<br>Asset Management Overview - 1 | |
|---|---|
| Learning Objectives | 1. To be able to start with the assignments<br>2. To be able to define the basic principles of asset management<br>3. To understand the scope and purpose of asset management<br>4. To understand the concept of added value<br>5. To be able to describe the three main roles/functions in asset management |
| Lecture | Topics<br>*Course overview, introduction to the assignments.*<br>*Asset Management, Asset Management Definitions, ISO 55000, Asset Management System, Asset Management Roles, Added Value, Performance Management, Risk, Cost, Alignment or Line of Sight, Asset Management Decision Making, Life Cycle Activities.* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 - Asset Management Overview<br>3. Hastings, N. A. (2015). Physical Asset Management (Hastings, 2015)<br>• Chapter 1: General Introduction<br>• Chapter 2: Structure and Activities<br>• Chapter 29: ISO 55000 Series Standards<br>4. The Institute of Asset Management , Asset Management – An Anatomy v3 (2015) (The Institute Of Asset Management, 2015)<br>5. Optional: ISO 55000-series (ISO, 2014a, 2014b, 2014c) |

| Week 2.2<br>RCM and FMECA | |
|---|---|
| Learning Objectives | 1. To understand and apply risk based maintenance strategies<br>2. To be able to assess asset risk (criticality)<br>3. To be able to define maintenance strategies and intervals<br>4. To understand failure patterns and uncertainties<br>5. To be able to critically evaluate the added value of risk based maintenance strategies in a broader asset management perspective<br>6. To understand the information need for risk based maintenance |
| Lecture | Topics<br>*RCM, Risk Based Maintenance, Physical Decomposition, Functional Decomposition, FMECA, Failure Mode, Effect and Criticality Analysis, Risk Matrix, Maintenance Concepts, Preventive Maintenance, Predictive Maintenance, Run to Failure Maintenance, Corrective Maintenance, Failure Patterns, Budgeting, Monitoring, Evaluation, Uncertainties.* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 RCM and FMECA<br>3. Hastings, N. A. (2015). Physical Asset Management (Hastings, 2015)<br>• 21.6 Failure Patterns and Causes<br>• 21.7 Failure Patterns Discussion<br>• 21.10 Failure Mode and Effect Analysis<br>• 21.11 Root Cause Analysis<br>• 21.12 Condition Monitoring<br>• 21.13 Reliability Centered Maintenance<br>4. Optional: van den Boogaard, J. and K. van Akkeren, (2012) Guidelines for Risk-based Operations and Maintenance. Rijkswaterstaat. (van den Boogaard & van Akkeren, 2012)<br>5. Optional: Moubray, J. (1997). Reliability Centered Maintenance II, (Moubray, 1997b). |

| | |
|---|---|
| **Week 2.3**<br>**Navigation Lock Hansweert – Case Study Explanation** | |
| Learning Objectives | 1. To be able to start case study assignment<br>2. To understand the context and background of the case study |
| Lecture | Topics<br>*Rijkswaterstaat, Principles of Lock Operation, Hansweert, Brief description of AM decision making methods used within Rijkswaterstaat Case Study Assignment, Method Description Assignment* |
| Literature | 1. Reader CME1210 – Case Description<br>2. Sheets CME1210 Guest Lecture<br>3. Sheets CME 1210 Assessment Criteria Case and Method Assignment |

| | |
|---|---|
| **Week 2.3**<br>**Reliability and Availability of Components** | |
| Learning Objectives | 1. To understanding the concept of reliability<br>2. To understanding the concept of steady state availability<br>3. To be able to assess and determine the reliability and availability of components<br>4. To understand the reliability functions and the use of stochastic models<br>5. To be able to critically evaluate the added value of reliability and availability calculations in a broader perspective of asset management |
| Lecture | Topics<br>*Object Reliability, Object Availability, Survival, Reliability Function, Cumulative Distribution Function (CDF), Probability Density Function (PDF), Hazard function, Mean Time To Failure (MTTF), Mean Time To Repair, Failure Rate, Uptime, Downtime, Examples of Steady State Availability Calculations* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 Reliability and Availability of Components<br>3. Hastings, N. A. (2015). Physical Asset Management (Hastings, 2015)<br>• 21.1 Introduction<br>• 21.2 Reliability<br>• 21.3 Specification and Testing<br>• 21.4 Design for Reliability<br>• 21.5 Managing the Reliability of In-service Assets<br>• 21.8 Failure Reporting<br>• 21.15 Availability<br>• 21.16 Availability Related to Total Time<br>• 21.17 Maintenance Effectiveness<br>• 21.20 Maintainability<br>• 21.21 Maintainability Measure<br>4. Optional: Schüller, J.C.H., et al.(1997). Methods for Determining and Processing Probabilities (Schüller, Brinkman, van Gestel, & van Otterloo, 2005)<br>5. Optional: Birolini, A. (2014). Reliability Engineering, Theory and Practice (A. Birolini, 2014) |

| Week 2.4<br>Reliability and Availability of Systems | |
|---|---|
| Learning Objectives | 1. Understanding the concept of reliability and availability of systems<br>2. Modelling of serial and parallel systems<br>3. Understanding the concept of redundancy<br>4. To assess a basic risk optimisation analysis<br>5. Using basic techniques like Reliability Block Diagram (RBD), Event Tree Analysis (ETA) and Fault Tree Analysis (FTA) to model and calculate reliability and availability of systems<br>6. Using Boolean algebra to handle common cause failures<br>7. To critically evaluate the results and validity of (complex) reliability and availability calculations |
| Lecture | Topics<br>*System Reliability, System Availability, Serial Systems, Parallel Systems, Active Redundancy, M out of N Redundancy, Reliability Block Diagram, Risk Optimisation, Event Tree Analysis, Fault Tree Analysis and Quantification, Common Cause Failures, Boolean Algebra, Application of Boolean Algebra* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 Reliability and Availability of Systems<br>3. Vesely, W. *et al* (2002). Fault Tree Handbook with Areaspace Applications (Vesely et al., 2002)<br>• Chapter 4: The Fault Tree Model<br>• Optional: Other chapters<br>4. Schüller, J.C.H. et al (2005). Methods for Determining and Processing Probabilities (Schüller et al., 2005)<br>• Chapter 10: Event Tree<br>• Optional: Other Chapters<br>5. Optional: Birolini, A. (2014). Reliability Engineering, Theory and Practice (A. Birolini, 2014) |

| Week 2.4<br>Life Cycle Costing | |
|---|---|
| Learning Objectives | 1. To understand the concept and application of Life Cycle Costing in the context of asset management<br>2. To understand the importance of the boundary constraints and input for LCC calculations<br>3. To prepare realistic cash flow diagrams and scenarios<br>4. To conduct an LCC analysis for new investments and comparing investment alternatives<br>5. To critically evaluate results of LCC calculations in the context of asset management |
| Lecture | Topics<br>*LCC, Cash Flow, Life Cycle, Net Present Value, Equivalent Annual Cost, Discount Rate, WACC, Inflation, dealing with equal lives and unequal lives.* |
| Literature | 1. Reader CME 1210<br>2. Sheets CME1210 Life Cycle Costing Analysis<br>3. Hastings, N. A. (2015). Physical Asset Management (Hastings, 2015)<br>• Chapter 5: Financial Methods<br>• Chapter 8: Life Cycle Costing<br>4. Watts J.M., R. E. Chapman - Handbook of Fire Protection Engineering, chapter 7: Engineering Economics (Watts & Chapman, 2008)<br>5. Optional: Park, C.S. (2015). Contemporary Engineering Economics 6$^{th}$ ed. (Chan S. Park, 2015) |

| Week 2.5<br>Methodology and Academic Skills | |
|---|---|
| Learning Objectives | To be able to practice<br>1) Critical thinking<br>2) Problem solving<br>3) Writing reports<br>4) Judgemental skills<br>5) Reasoning |
| Lecture | Topics<br>*Academics skills for problem solving, report writing and reasoning, Research Methodology, Reporting, Competences KSA, Professionalism, Purpose – Scope – Viewpoint, Methods, Techniques, Models and Tools, Criteria for Application of Models and Tools, Quality of Information* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 |

| Week 2.5<br>Performance Management | |
|---|---|
| Learning Objectives | 1. To explain the relationship between Asset Management and Performance Management<br>2. To understand decision making and control at different levels<br>3. To describe Asset Management from a system's perspective<br>4. To understand the difference between Asset Management and Maintenance<br>5. To be able to describe the activities/process steps within Maintenance |
| Lecture | Topics<br>*Performance Management, Line of Sight, Network Decomposition, Service Level Agreements, Key Performance Indicators, Monitoring and Evaluation, Asset Management within Rijkswaterstaat, Governance of Rijkswaterstaat using an SLA, Six Stage Model, Optional: Outsourcing of Activities.* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 Performance Management<br>3. Neely, A. et al (1997). Designing Performance Measures: A Structured Approach (Neely, Richards, Mills, Platts, & Bourne, 1997)<br>4. Arthur, D., et al (2015). Asset Planning Performance Management, Tampere. (Arthur, Schoenmaker, Hodkiewicz, & Muruvan, 2015) - See Brightspace<br>5. Hatcher, W. E., Whittlestone, A. P., Sivorn, J., & Arrowsmith, R. (2014). A Service Framework for Highway Asset Management, London. (Hatcher, Whittlestone, Sivorn, & Arrowsmith, 2014) – see Brightspace<br>6. Optional: Schoenmaker, R. (2011) De ingeslagen weg, chapter 3 (Schoenmaker, 2011)<br>7. Optional: Schoenmaker, R., & Verlaan, J. G. (2013) Analysing Outsourcing Policies in an Asset Management Context: A Six-Stage Model (Schoenmaker & Verlaan, 2013) |

| Week 2.6<br>Asset Management overview - 2 | |
|---|---|
| Learning Objectives | 1. To be able to apply the basic principles of Asset Management<br>2. To understand the scope and purpose of Asset Management<br>3. To be able to apply a generic model of Asset Management on a given problem |
| Lecture | Topics<br>*Asset Management Model, Organisational Strategic Plan, Strategy and Planning, Asset Management Decision Making, Asset Information, Life Cycle Delivery, Risk and Review, Organisation and People, Application on a case* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210<br>3. The Institute of Asset Management. (2015). Asset Management - An Anatomy (The Institute Of Asset Management, 2015)<br>4. Optional: GFMAM (2014). The Asset Management Landscape (GFMAM, 2014) |

| | |
|---|---|
| **Week 2.6 – 2.7**<br>**Progress Case Study** | |
| Learning Objectives | 1. To provide guidance on case study progress |
| Lecture | Topics<br>*Presentation and Discussion on Problem Definition, Research Question, Method, Underpinning Tool Selection, plus content provided by students* |
| Literature | N.a. |

| | |
|---|---|
| **Week 2.7**<br>**Auditing 1 - Theory** | |
| Learning Objectives | 1. To be able to perform a non-financial audit/assessment |
| Lecture | Topics<br>*Audit, Agency Theory, Proof, Trust, Objective, Materiality, Ethics, Scoping, Audit Risk, Audit Cycle, Audit Dimension, Audit Risk, Audit Cycle* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210 |

| | |
|---|---|
| **Week 2.8**<br>**Auditing 2 – Practice Workshop** | |
| Learning Objectives | 1. To be able to operationalize audit objectives<br>2. To be able to use the audit framework<br>3. To be able to start with the audit assignment |
| Lecture | Topics<br>*How to Audit, Operationalisation of Objectives, Level of Assurance, Efficiency, Auditor Requirements, Audit Framework, Exercise with Building Audit Framework, Assessment Criteria for the Audit Assignment* |
| Literature | 1. Reader CME1210<br>2. Sheets CME1210<br>3. Sample audit framework – see Brightspace |

| | |
|---|---|
| **Week 2.8, 2.9, 2.10**<br>**Consultation on Request** | |
| Learning Objectives | 1. To be able to continue with the audit assignment |
| Lecture | *The lecturers are available for consultation during the final weeks of period 2 on Mondays and Wednesdays, during the 5th and 6th hour.*<br>*The consultation meetings are on request. You have to make an appointment for the meeting. You will prepare yourself to make sure that the proper items are addressed.* |
| Literature | N.a. |

# 4 INFRASTRUCTURE ASSET MANAGEMENT

## 4.1 What is Asset Management?

*Asset* and *asset management* can be defined in many ways. We will look at some of the definitions, their differences, and similarities in the lectures. What these definitions more or less have in common is that they see asset management as a systematic process, embracing all phases of the life cycle of an asset, based on sound business practices and economic rationale. Asset management is not just maintaining assets for the sake of the assets, but is focused on providing and applying methods to facilitate decision making for achieving the organisation's objectives.
As a starting point we will use a very general definition of asset management, which is given by the asset management standard ISO55000 (ISO, 2014a):

> *Co-ordinated activity of an organisation to realize value from assets.*

In the same standard assets are described as:

> *An item, thing or entity that has potential or actual value to an organisation.*

And realisation of value is described as:

> *Realisation of value will normally involve a balancing of costs, risks, opportunities and performance benefits.*

In the lecture, we will discuss the abstract definitions and give some examples of how organisations have implemented these definitions.

Why *infrastructure* asset management?
According to the ISO55000 assets can be almost anything, as long as they have potential or actual value to an organisation. Defined like that, assets can be tangible or intangible like brand names or goodwill. Or it can be humans. Or finance. We need focus. Therefore, in this course we focus on assets that are part of an infrastructure. Infrastructure, transportation infrastructure to be precise, has certain characteristics, like high capital intensity, long (technical) life time, no residual value, and often public ownership. And the owner has multi-valued objectives, like social welfare, safety, economic growth, etcetera.

What are infrastructure assets?
Infrastructure assets are stationary systems (or networks) that serve defined communities where the system as a whole is to be maintained at a certain level of service (NAMS Group, 2006). That level of service need not be static.
Typical infrastructure assets are:

- Transportation networks (road, rail, waterways, ports, airports, bridges);
- Water utility assets (production and transport);
- Waste water assets (treatment plants and transport);
- Energy systems (production, transmission and distribution);
- High water protection assets (dikes, locks).

Some of the key elements in infrastructure asset management are (NAMS Group, 2006):

- Taking a life cycle approach;
- Developing long term cost effective management strategies;
- Providing a defined level of service and monitoring performance;
- Understanding and meeting the demands caused by changes;
- Managing risks.

## 4.2 Principles of Asset Management

We identify four pillars or principles of asset management. First, asset management is about creating *value* for the organisation. That implicates that, what defines *value* has to be operationalized, has to be clear to the organisation, its departments and the staff. Decision making that results in creating, acquiring, repairing, maintaining or disposing assets should be done with the organisational goals in mind. This decision-making will always try to find a balance between costs, performance and risks.

Second, asset management is about *alignment* or line of sight. The organisational goals have to be translated in asset management objectives and activities to achieve those objectives. We will pay a lot of attention to these first two principles in the lectures and in the assignments.
The third principle, which will not be dealt with in this course, is about strong *leadership* from the top of the organisation (as with quality management or environmental management) with commitment, vision and a focus on continuous improvement.
The fourth principle is *integration*. This is about development and implementation of interrelated processes and that help achieve the organisational goals. This fourth principle will be illustrated in a separate lecture based in the conceptual model of asset management of the Institute of Asset Management (The Institute Of Asset Management, 2015).

### 4.2.1 Control – Governance

Where we previously mentioned that asset management is all about achieving the organisational objectives, it is interesting to draw a parallel between business management and asset management. We will use the (general) conditions for effective control of systems from De Leeuw (Leeuw, 2002) and apply this to infrastructure asset management. You cannot be effective in controlling a system (re: system of assets) when you are not aware of the goal (purpose) of the system. De Leeuw identifies six conditions for effective control:

1. a specific goal for the system;
2. a model of the system;
3. information about the status of the system parameters;
4. information about the parameters of the environment;
5. sufficient control variety;
6. sufficient processing capacity.

We will discuss all six conditions in one of the lectures and apply them to asset management.

### 4.2.2 Performance Management

The second principle of asset management, the principle of alignment brings us to the basics of performance management. The objectives of the organisation have to be translated into asset management objectives, asset objectives and activities. At all these different levels, we need indicators to measure the performance and to set targets. Based on (NCHRP, 2010) several levels of performance measures can be identified:
*At the organisational policy level:* Performance measures should be identified in response to goals and objectives, not the other way around, Performance measures can help in formulating goals and setting realistic objectives. A performance-based approach requires thinking through the priorities of all organisational goals and making decisions on the most important goals and objectives to be met.
*At the planning and programming level.* Here performance measures are used to structure the comparison of different investment options at the network and project levels. These performance measures should be consistent with organisational objectives. The use of performance measures can inform the decision-making process and communicate effectively the consequences of choices.
*At project or programme level.* Here performance measures are used for tracking the actual versus planned mix of projects and (maintenance) programmes.
*At the system or network level.* System monitoring and performance results are critical components of performance-based planning. Monitoring is based on ongoing inspections or observations of the asset system to track performance trends and assess the impacts of investments already undertaken.
In one of the lectures we will go into more detail of the pros and cons of performance measurement and management. In the case study assignment, the asset management objectives of the case are given. These objectives have to be interpreted by you and alternative objectives or targets have to be given.

## 4.3 Decision-making and Decision-making Methods

Across the life cycle of the assets, be it the whole asset portfolio, asset system or individual assets, decisions about creating, acquiring, replacing, modifying, maintaining, repairing or disposing assets have to be made. Asset management can be seen as an integration framework of methods, that supports decision-making and, when appropriately applied, delivers value to the organisation. The question then becomes: When to apply which method and on which conditions?

### Decision-making Methods

At the end of the reader we have provided a long list of methods. These methods are not specifically designed for asset management, nor are they all widely applicable within asset management. A good asset manager has to be able to evaluate the applicability of methods and techniques and can give the arguments for the use of the chosen methods and techniques. Next, a good asset manager is capable of appropriately applying the method or technique. The asset manager should also be able to analyse the application of the methods and techniques and the outcome of the decision-making process executed by others.

For the purpose of this course we focus on a limited number of methods, tools:

- Root Cause Analysis
  - Ishikawa diagram
  - 5 Why's
- Failure Mode, Effect and Criticality Analysis (as part of reliability centred maintenance)
- Reliability and Availability Analysis
- Life Cycle Costing Analysis

## 4.3.1 Root Cause Analysis

Root Cause Analysis (RCA) is an approach for identifying the underlying cause or root cause of a failure or incident. RCA is in its simplest form based on three main questions:

1. What is the problem?
2. Why did it happen?
3. What can be done to prevent it from happening again?

Execution of an RCA is part of the quality management cycle as shown in figure 1.

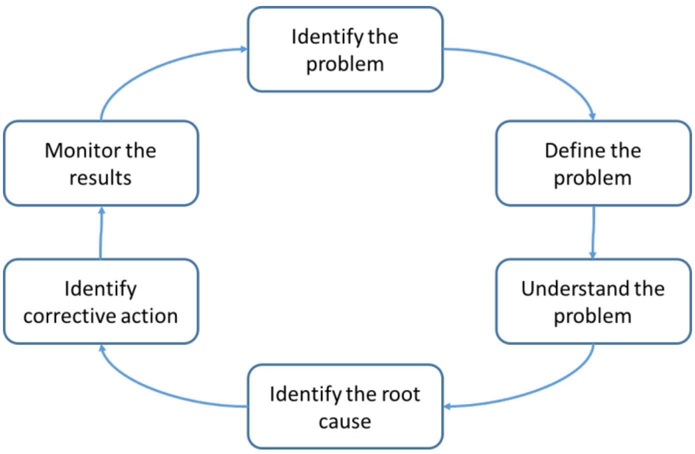



Figure 1 RCA and the Quality Management Cycle

Here we want to mention two methods to execute an RCA:

- Ishikawa or Fishbone diagram
- Gemba Gembutsu or 5 Why's

### Ishikawa or Fishbone diagram

These diagrams, also known as cause & effect diagrams are a technique to create causal diagrams that show the (possible) causes of an event. This event can be intended or unintended. The name fishbone refers to the appearance of the resulting diagram. A principle diagram is given in figure 2. The most commonly used main factors (main fishbones) are:

- Materials;
- Measurement;
- Machines;
- Man (People);

- Methods (Procedures);
- Environment.

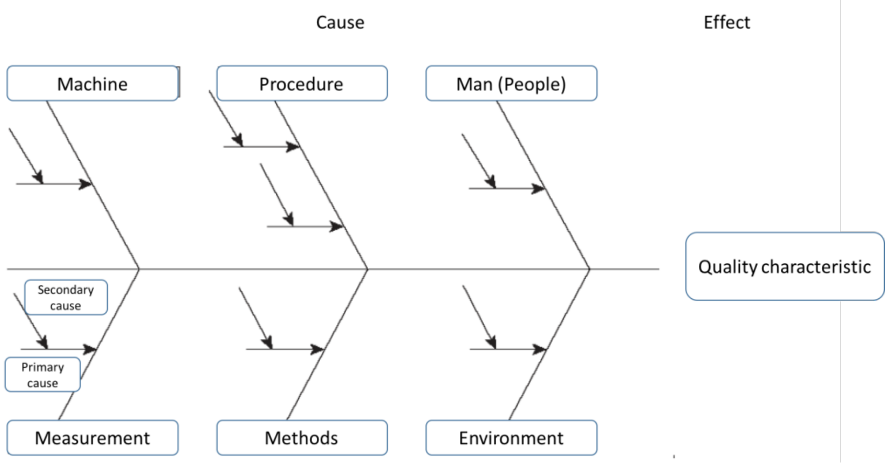



Figure 2 Sample Ishikawa Diagram

These six main factors are not prescriptive. Every quality characteristic (failure, incident) may have its own main factors. The way to elucidate the possible cause within the main factors is by brainstorming or doing interviews with experts by going through these steps:
1. Decide on description of quality characteristic or effect;
2. Write description quality characteristic side of the diagram;
3. Write main factors that may be contributing to the effect;
4. Write detailed factors in the fishbone that may be causes of the effect;
5. Check if every cause is in the diagram.

Once every possible cause is in the diagram, first identify the causes that contribute most to the effect and next identify the causes you have control over. Then concentrate on finding solutions to eliminate these causes.

### Gemba Gembutsu or 5 Why's

Another simple technique to identify the root cause is called Gemba Gembutsu or the 5 Why's. Gembutsu is a Japanese word that means 'real thing' and gemba means 'actual place' and together they refer to the Japanese mind-set of getting as close to the problem as possible and as close to the actual place using actual data. Do not rely on second hand observation. The 5 Why's refers to the practice of asking 'Why' five times. The procedure starts with identifying the problem statement of quality characteristic. The number of 'Why's' is flexible but should at least be five. Asking 'Why' a sufficient number of times should lead to the root cause and should prevent you from addressing a symptom of the problem. The answer to the last 'Why' gives you the root cause of the problem.

The 5 Why's technique is also very applicable in your audit assignment. In this assignment, you will individually audit the case study report of another group. Part of the assignment is giving recommendations for improvement of the case study report. Some sort RCA has to be executed to be able to give the right recommendations, asking the 5 Why's will help you here.

Five Why's

Problem Statement - Symptom

- You are on your way home from university and your car starts stalling and finally stops.

1. Why did your car stop?
   - Because it ran out of gas.
2. Why did it run out of gas?
   - Because I didn't buy any gas on my way to the university.
3. Why didn't you buy any gas this morning?
   - Because I didn't have any money on me.
4. Why didn't you have any money?
   - Because I left my wallet at home.
5. Why did you leave wallet at home?
   - I didn't leave it at the usual place with my keys and driver's licence

Textbox 1 Example of the 5 Why approach

## 4.3.2 Failure Mode Effect & Criticality Analysis

A Failure Mode Effect & Criticality Analysis (FMECA) is a method to assess the risks of a functional failure of an asset in order to define appropriate risk control measures such as:

- Maintenance, modifications or replacements;
- Impact reducing measures (contingency measures, protective devices);
- Process related measures (e.g. operations, quality control, corrective actions).

An FMECA (Hastings, 2015) is normally part of a reliability centred maintenance (RCM) approach (Moubray, 1997a). This is a systematic approach to assess asset risks, based on performance standards and risk acceptation levels. Next steps in the approach are to define risk control maintenance measures, implement them, monitor and take corrective actions when required.

An FMECA is summarised by the following steps:

1. Define the system (segmentation);
2. Define the function;
3. Define loss of function;
4. Define all possible failure modes;
5. Assess failure probabilities;
6. Assess consequences and severity;
7. Assess criticality.

In the lectures, we will further elaborate on these steps.
An important tool in assessing risks (to define the criticality) is a risk matrix.

| | | | | | | | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Impact** | | | | | **Mean Time Between Failure = 1/ Failure Rate** | | | | | | |
| | | **Safety** | **Environment** | **Product quality** | **Financial consequences** | **Reputation** | MTBF ≥ 100 yr | 100 yr < MTBF ≥ 25 yr | 10 yr < MTBF ≥ 25 yr | 10 yr < MTBF ≥ 5 yr | 5 yr < MTBF ≥ 1 yr | 1 yr < MTBF ≥ 0.1 yr | MTBF < 0.1 yr |
| | | | | | | | Less than 1 time per 100 year | 1 time per 25 years up to 1 time per 100 years | 1 time per 10 years up to 1 time per 25 years | 1 time per 5 years up to 1 time per 10 years | 1 time per year up to 1 time per 5 years | 12 times per year up to 1 time per year | More often than monthly |
| | | | | | | | This type of failure has never occurred but we cannot exclude it | I will probably face this type of failure one's in my working life | I will probably face this type of failure twice in my working life | These types of failures will happen about four times in my career | Every couple of years I expect this to happen | A couple of times per year I expect this to happen | I know exactly what happened last month |
| | | | | | | | **1** | **2** | **4** | **8** | **16** | **32** | **64** |
| E1 | 1 | No consequences. | Negligible spillage or emission. | Compliance to internal standards. | < € 2,000 | Less than 10 individual complaints. | 1 | 2 | 4 | 8 | 16 | 32 | 64 |
| E2 | 2 | First aid accident. Irritation. | Limited emission or damage within site boundaries. | Short non compliance (hours) to internal standards. | < € 10,000 | More than 10 Individual complaints without media attention. | 2 | 4 | 8 | 16 | 32 | 64 | 128 |
| E3 | 8 | Light and non permanent injury. Temporarily adapted work. | Non compliance to legal requirements with no environmental consequences. | Incidental non compliance (hours) to legal requirements. | € 10,000 - € 100,000 | Local disturbance / local press. | 8 | 16 | 32 | 64 | 128 | 256 | 512 |
| E4 | 16 | Serious injury (temporary disablement). Absent. | Non compliance to legal requirements with moderate environmental consequences. | Temporary non compliance (days) to legal requirements. | € 100,000 – € 1,000,000 | Regional disturbance / regional press. | 16 | 32 | 64 | 128 | 256 | 512 | 1024 |
| E5 | 32 | Very serious permanent injury. Disabled. Fatality. | Non compliance to legal requirements with serious environmental consequences. | Long term non compliance (weeks) to legal requirements. | € 1,000,000 – €10,000,000 | National disturbance / national press. | 32 | 64 | 128 | 256 | 512 | 1024 | 2048 |
| E6 | 64 | Multiple fatalities. | Permanent and severe environmental damage. Catastrophic. | Structural non compliance to legal requirements. | > € 10,000,000 | International disturbance / international press. | 64 | 128 | 256 | 512 | 1024 | 2048 | 4096 |

Figure 3 Example of a risk matrix

The left columns show the organisational values and different impact criteria. This is where you can see the link with one of the principles of asset management: creating value. Ideally these values are fully achieved. But due to risks that materialise, the value may not be fully achieved and negatively influenced in varying severity. It is really important that these organisational values and the severity gradations are well defined. The right columns show the different frequencies (failure rates) in which the risks can occur. Defining the impact criteria and setting the risk acceptation levels (the green, yellow and red areas) is a corporate responsibility.
Based on the risk assessment, risk control maintenance measures can be defined. These measures should:
1. reduce the risk to an acceptable level;
2. be technically feasible;
3. be economically worthwhile.

## 4.3.3 Reliability and Availability Analysis

As mentioned in section 4.2, asset management is about alignment or line of sight. The organisational goals have to be translated in asset management objectives and activities to achieve those objectives. Reliability and availability of assets are important asset management objectives that contribute directly to the overall organisational goals. In this paragraph, we summarise the theory you will need in your case study assignment on reliability and availability analysis. Examples and more in-depth information are given in the lectures.

### The basics of reliability and availability

A non-repairable component will only fail once and the time to the first and only failure is designated with Mean Time To Failure (MTTF). Repairable components fail more than once and are put in to operation again after repair. In this situation, we speak about the Time Between Failures which is expressed as MTBF. In the following paragraphs the basics of reliability are explained for the MTTF for non-repairable systems. This theory however, also applies to the behaviour of the Mean Time Between one failure to the next for repairable components.
Four expressions are available to describe reliability characteristics: the reliability function R(t), the cumulative probability density function F(t), the probability density function f(t) and the hazard rate z(t)(Dhillon, 2005). Knowing one of these expressions is enough to know them all.

1) The **reliability R(t)** of a component is defined by the probability that a component will fulfil its function during a specified time. Reliability is measured by taking a population of the same type of components and measuring their survival in time.

$$R(t) = \frac{N(t)}{N(0)},$$

with:
R(t) = Reliability function
N(t) = number of components still alive at t
N(0) = number of components at t = 0 (the original population)

2) **Unreliability F(t)** is the opposite of reliability. It measures proportionally how many components from an original population have failed at a specified time since the start. Thus, the probability of a failure between [0,t].

$F(t) = 1 - R(t)$, with **F(t) = cumulative probability density function**.

3) Knowing proportionally how many components have failed before a specified time allows us to calculate the number of components that fail in each unit of time. This is the probability of failure during a small unit of time and given by:

$f(t) = \frac{F(t+\Delta t) - F(t)}{\Delta t}$, with **f(t) = probability density function.**

4) The **hazard rate z(t)** measures the probability that a component will survive another time unit given the fact that it is still alive at time t. The hazard rate is a *conditional* probability. Comparing this to human life, z(t) expresses the probability that someone at the age of 80 is more likely to die in the next year than someone at the age of 20.

$$z(t) = \frac{f(t)}{1 - F(t)} = \frac{f(t)}{R(t)}.$$

Other important characteristics of reliability are the conditional reliability, the Mean Time to Failure and the average failure rate **λ**.
The **conditional reliability R(t+ΔT|t)** is the probability that a component will survive time Δt given the fact that it is still functioning at t:

$$R(t + \Delta t \mid t) = \frac{R(t+\Delta t)}{R(t)}.$$

The **Mean Time to Failure** is the average life (average age of failure) of the components in the population and defined as:

$$MTTF = \int_0^\infty R(t)dt.$$

The **average failure rate λ** (not to be confused with the hazard rate z(t)) is the reciprocal of the MTTF.

$$\lambda = \frac{1}{MTBF}.$$

The reliability of any component can be measured and described with these expressions, provided that sufficient data on failure behaviour of similar components is available. In practice failure behaviour that is often seen is already expressed in reliability characteristics. Three common distributions are the exponential distribution, the normal distribution and the Weibull distribution.

Table 3 Common Reliability Distributions

| The exponential distribution | The normal distribution | The Weibull distribution |
|---|---|---|
| $R(t) = e^{-\lambda t}$ | $R(t) = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$ | $R(t) = \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$ |
| $F(t) = 1 - R(t) = 1 - e^{-\lambda t}$ | $F(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt$ | $F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$ |
| $f(t) = \lambda e^{-\lambda t} = \lambda R(t)$ | $f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(t-\mu)^2}{2\sigma^2}}$ | $f(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$ |
| $z(t) = \lambda$ | $z(t) = \frac{e^{\frac{-(t-\mu)^2}{2\sigma^2}}}{\int_{t}^{\infty} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt}$ | $z(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1}$<br>β > 1, z(t) decreasing<br>β = 1, z(t) constant<br>β = 1, z(t) increasing |

Up to this point we presented several ways to describe the behaviour to the first failure for a non-repairable component (MTTF) and/or the behaviour of the n$^{th}$ failure to the (n+1) failure of a repairable component (MTBF).

In practice, we normally replace a non-repairable component after failure and we repair a repairable component after failure. The major difference between these two situations is that after replacement, the condition is often '*as good as new*' and after repair, '*as bad as old*'. To describe reliability behaviour of identical replacements the literature offers the so called *renewal theory* (Alessandro Birolini, 2014). To describe the reliability behaviour of multiple repairs the literature provides *stochastic point processes* (the homogenous and non-homogenous Poisson process, HPP and NHPP)(Rigdon & Basu, 2000). These theories are mentioned for those interested in further specialisation on this matter and are not necessary for the case study assignment.

*Availability of components*

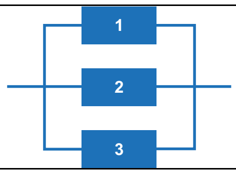
Availability is broadly defined as the proportion of the time that an asset can full fill its function. We distinguish point availability A(t), mission availability $A(t_1,t_2)$ and average or steady state availability $A_{ST}$ (Alessandro Birolini, 2014). Knowing the (cumulative) probability of a failure as a function of time, together with the mean time to repair or replace (MTTR) allows for calculating the time dependent point and mission availability. In practice the average or steady state availability is commonly used as a measure for availability. In this case the average failure rate or MTTF is used. The steady state availability is defined as:

$$A_{ST} = \frac{MTTF}{MTTF + MTTR}.$$

## Reliability and availability of systems

A system is built of several components. The reliability (or availability) and configuration of components determine the reliability (or availability) of the system. In other words: if we know the reliability behaviour to the first or next failure of the components, we also know the reliability behaviour to the first or next failure of the system that is composed of these components. The most common configurations are (a combination of) the serial and parallel configurations.

Table 4 Serial and parallel reliability and availability equations

| | |
|---|---|
|   | $R_s = R_1 \cdot R_2 \cdot R_3 \cdot \ldots$<br>$A_s = A_1 \cdot A_2 \cdot A_3 \cdot \ldots$ |
|   | $R_s = 1-(1-R_1)(1-R_2)(1-R_3)\ldots$<br>$A_s = 1-(1-A_1)(1-A_2)(1-A_3)\ldots$ |

By combining these basic equations many more complex systems can be modelled. When components simultaneously fail, the system will fail. Beware however, that this approach of calculating the reliability or availability of a system is limited to the first time to failure or the time from one failure to the next.

Reliability Block Diagrams

One technique for analysing the reliability of systems is called the reliability block diagram (RBD) technique. Figure 4 visualises a RBD. Each component is modelled with a block. The systems reliability is calculated with the serial and parallel reliability (or availability) equations.

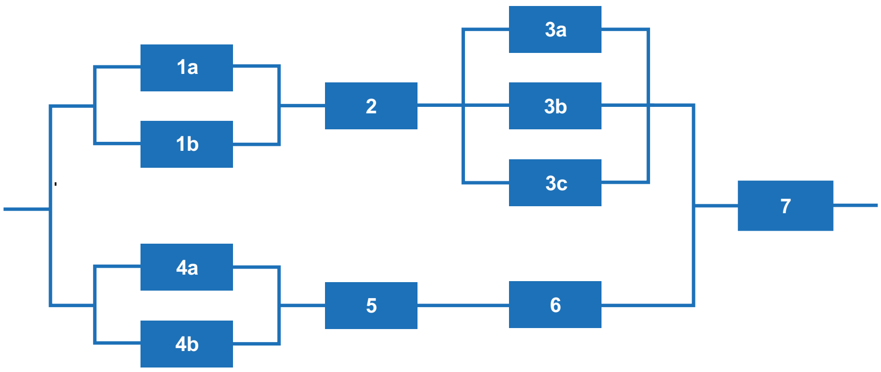



Figure 4 Reliability Block Diagram

A special note to think about in your case study assignment: preventive maintenance on a component is planned maintenance that will cause temporary unavailability of a component which affects the intrinsic system reliability.

## 4.3.4 Fault tree analysis

The fault tree analysis (FTA) is another technique that can be used to calculate the systems reliability and/or availability. One starts with an unwanted top event and descends to underlying causes to end at basic events (causes that are not further decomposed). In its most simple form two gates are used to unravel above lying causes: AND and OR gates.

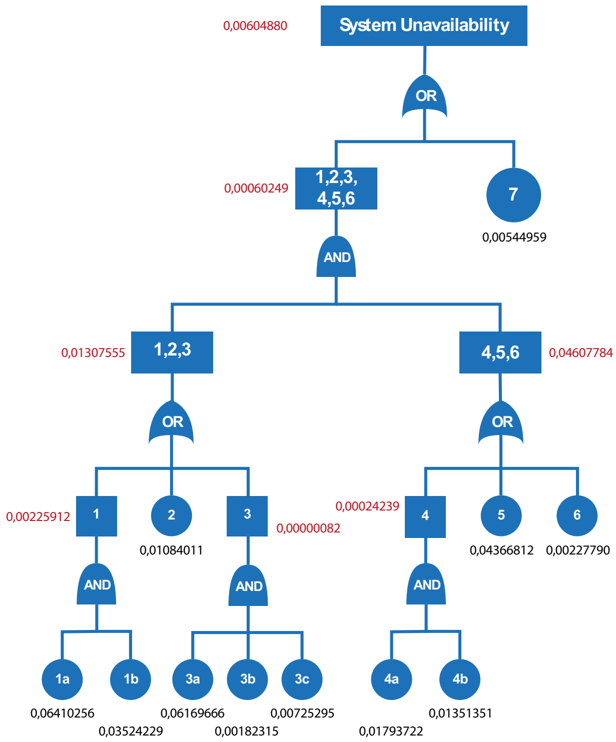
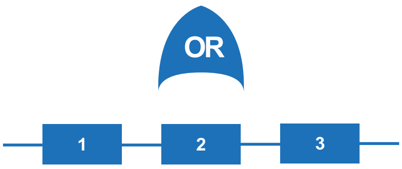
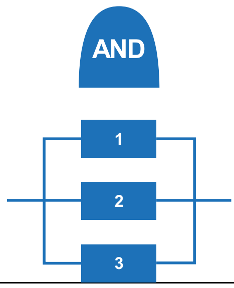



Figure 5 Fault Tree derived from the RBD in figure 4

FTA's and RBD's are in a way each other's opposites. The fault tree analysis focuses on unreliability or unavailability. The reliability block diagram analysis focuses on reliability or availability. When the unreliability of the basic events is known, the system's unreliability can be calculated by using the equations in table 5.

Table 5 Serial and parallel reliability and availability equations

| | |
|---|---|
|   | $F_s = 1-(1-F_1)\cdot(1-F_2)\cdot(1-F_3)...$ <br> $NA_s = 1-(1-NA_1)\cdot(1-NA_2)...$ |
|   | $F_s = F_1 \cdot F_2 \cdot F_3...$ <br> $NA_s = NA_1 \cdot NA_2 \cdot NA_3...$ <br> Assumption for $NA_{1,2,3,...}$: simultaneous repairs |

### 4.3.5 Life Cycle Costing Analysis

Asset management is about balancing performance, risks, performance benefits and life cycle costs. Engineers mostly use life cycle costing analysis (LCCA) to compare the life cycle costs of different engineering options like new investments, renovations, replacements and maintenance optimisations. Life cycle costs are weighted against performance and risk (reduction). When comparing life cycle costs one has to take the time value of money into account. A life cycle costing analysis is part of the case study assignment. As a consequence of interest and inflation, we cannot simply add or subtract money that is gained or spent in different years in time. To account for the time value of money future cash flows are converted to their present values according to (C.S. Park, 2011):

$$PV = FV \cdot \frac{1}{(1+i)^n},$$

with:
PV : Present value of a future value [currency]
FV : Future value (cash flow in year n) [currency]
i : Real or inflation free interest or discount rate [-]
n : Year number (or month, depending on the time unit chosen) [time unit]

The so-called Net Present Value (NPV) includes cash flow in and out over a number of years.

$$NPV = I_0 + \frac{FV_1}{(1+i)^1} + \frac{FV_2}{(1+i)^2} + \ldots\ldots + \frac{FV_n}{(1+i)^n}$$

In the comparison of life cycle costs of different engineering options, '*cash flow in*' is commonly not differential (equal for all alternatives) and therefore neglected. In that case, we talk about cost models and present value analysis or PV-analysis instead of NPV-analysis. It is a semantic issue.
The (N)PV can be transformed to Equivalent Annual Cost (EAC) over the life cycle of projects or assets conform (C.S. Park, 2011):

$$EAC = PV \cdot \frac{i(1+i)^n}{(1+i)^n - 1}.$$

The EAC is practical if one is interested in comparing the cash flows of projects or assets with unequal lives under the assumption of a continuous repeatability of life cycle cash flows.
Cash flows represent the life cycle costs such as:

- Acquisition:
  - Investment including transport and installation;
  - Sales of old installation, salvage value, taxes on revenues;
  - Demolition, cleaning up;
  - Stock items, warehouse, liquid capital, software.
- Ownership:
  - Sales and taxes on profit;
  - Salaries;
  - Operation and Maintenance;
  - Materials and consumables.
- Disposal:
  - Demolition / Cleaning up;
  - Salvage values and taxes on revenues.

Cash flow represents real operational cash and does not include (historic) depreciation, long-term interest expenses and sunk costs.

# 5 ASSIGNMENTS

Table 6 gives an overview of the assignments and their deadlines.
Paragraph 5.1 gives the generic assessment criteria for both your assignments. Read them carefully.
Paragraph 5.2 and 5.3 give a short description of each assignment and the assessment criteria.
Each assignment will be introduced in the lectures, including more details on the assessment criteria.

Table 6: Overview of assignments and deadlines (G = group, I = individual)

| | Assignment | Deadline |
|---|---|---|
| 1. | Case study (G) | Friday, 12 Jan '18, 10 AM (end of week 2.7) |
| 2. | Audit report (I) | Friday, 16 Feb '18, 10 AM (end of week 3.1) |

## 5.1 Assessment Criteria - General

We have general assessment criteria for **both** assignments in this course.
The reports should meet the requirements of a good scientific report, defined as:

- The report has a clear line of reasoning and structure;
- The report is to the point;
- Graphs, illustrations and tables are self-explanatory, relevant, have a description and are numbered;
- Appendices are appropriately used;
- It has correct use of English language with little or no spelling and/or grammatical errors;
- The report is without any plagiarism;
- Citations and references are consistently used (e.g., Harvard, Numbered or APA).

> Make sure that you use information from reliable and renowned sources.
> Not every Internet source is reliable, especially beware of the first one you *stumble* upon.
> The quality of your sources will influence the grading.

## 5.2 Description of the Main Tool as Used in the Case Study

Every case study will use a main tool, method or technique. We will discuss this main tool/method/technique in the lectures and workshops, for a short description of a few, see chapter 4. You have to give a description of the main tool/method/technique in the case study report and in the audit report. Your description has to show a good understanding of this method, its application in the context of the case study and its limitations. Therefore, your description has to include a set of given topics. Topics that need to be covered, in the context of the case study, are:

- Definition, description;
- Graph, illustration explaining the method;
- Application of the tool and the limitations;
- A small example of the application of the method in an asset management context.
  *This example has to be your own example, not an example copied and pasted from other sources.*
  *Make sure that your example is related to infrastructure asset management and the case*
- Literature (search);
- Focal area for this method in asset management - *Details will be given in the lectures*
- Reference to applicable NEN, EN, ISO or IEC standards

An explanation of these topics will be given during one of the lectures.

It is important that you:

1. Show your understanding of the (application of the) method/technique.
   See the topics above.
2. Use your own words in the assignment – it is tempting to copy/paste information from your sources – do not be tempted – see flyer on fraud/plagiarism on Brightspace.

3. Identify the focal area in asset management using the six-stage model or IAM model and explain your choice.
4. Include your own conclusion about the applicability of your method/technique in the case study asset management – this links with the Methodology lecture

## 5.3 Group Assignment – Case Study

### Introduction

For this assignment, you will work in a group of 5 or 6 students. The lecturer will select the members of each group in the second week of the course. Each group has to find an answer to one of the problem statements mentioned below. The lecturer will assign a problem statement to each group. Each group has to translate the problem statement into a solid research question and write a report answering this research question, using a tool that is appropriate. The group will act as a consulting agency that will advise the client (i.e. Rijkswaterstaat).

> Start early with interpreting the problem statement, designing a research question and selecting an appropriate tool for your case. This process takes time. The sooner you have understood your case, defined your research question and selected appropriate tools the more time you will have to carry out this case.

Two things are very important here. First, underpin how you have defined your research question from the problem statement. Second, it is important to underpin/motivate the selection of the tool. The context of your answer has to fit in the context of asset management of (physical) infrastructures. Pay attention to the motives for your choices. It is advisable to check for other methods or techniques, which may help you giving a good and balanced advice to the client. A long list of tools, methods or techniques is given at the end of this Study Guide together with some references for each method. This long list contains methods and techniques that may assist you in solving most asset management related problems and challenges. Some of them are less relevant for civil engineering assets than others, and you most probably have already addressed some of the methods or techniques in another context or another course.

> The client also demands that, after the case study report has been finished, the case study report is followed by an audit. This audit will be your individual assignment – see 4.3.

### The Case and the Problem Statements

Rijkswaterstaat operates and maintains the navigation lock at Hansweert. The two locks are an important link in a major shipping corridor between Rotterdam and Vlissingen, Terneuzen and Ghent (Belgium). A general description of navigation lock Hansweert is given in chapter 7.
Maintaining these locks is a crucial task for the regional department Zee & Delta of Rijkswaterstaat. This department needs advice on assuring the level of availability and maintainability of the navigation lock and its operating mechanism according to the demands of the Ministry of Infrastructure and Environment. Further optimisation is sought in the application of a life cycle costing strategy.

> Each group will be given one of the three following problem statements.
> All groups must include an answer concerning the interpretation of the service level requirements of the navigation locks within the shipping corridor.

### Problem 1. Availability of the Locks

Over the recent months, doubts have risen whether Rijkswaterstaat will be able to meet the performance requirements on availability of the locks in Hansweert within in the shipping corridor in the longer run. Is the present lock system capable of continuously meeting the service levels? What is a good interpretation of the

service level requirements? The SLA-PIN's[1] as described in chapter 7 are not clear. You need to pay attention to the performance requirement at corridor level and the contribution of the locks to this overall performance requirement. You will need to give a workable interpretation of the given SLA-PIN's.
Rijkswaterstaat wants you to focus on the navigation locks. What can Rijkswaterstaat do to assure the availability of the navigations locks of Hansweert? What are the basic events that cause downtime of the locks? Does Rijkswaterstaat need to implement improvements? Or looking at it the other way around: what are feasible targets for the availability of the locks? Important is not only to look at the short term, but also to take the longer term into account. Of equal importance is attention to what Rijkswaterstaat can do to minimize the consequences of (partial) systems failure.

## Problem 2. Maintainability

Over the years Rijkswaterstaat has developed maintenance plans for the navigation locks of Hansweert. These maintenance plans are based on design data, experience, historical data and advice from original equipment manufacturers. The plans are mainly preventive and time-based. A more modern approach is a risk-based approach that is linked to the functions, condition and required performance of the locks. What then are the functions of the locks and its components? What is a good interpretation of the service level requirements? The SLA-PIN's as described in chapter 7 are not entirely clear. You need to pay attention to the performance requirement at corridor level and the contribution of the locks to this overall performance requirement. You will need to give a workable interpretation of the given SLA-PIN's. Rijkswaterstaat recognises that the whole lock system is much encompassing. You will have to make a physical and functional decomposition of the lock system for further analysis and focus on the most critical parts. The rolling gates, their operating mechanism and their contribution to the required performance of the locks are a good starting point for a risk-based maintenance approach. Rijkswaterstaat is looking for a risk based maintenance strategy that not only covers the first five years but also gives insight in the longer term. Primary focus should be on the rolling gates and their operating mechanism.

## Problem 3. Life Cycle Costing

Rijkswaterstaat has already introduced the concept of life cycle costing in the decision-making process for weighing options in new build projects. Rijkswaterstaat also wants to introduce this concept in maintenance for optimising the costs in decision making for maintenance interventions. Rijkswaterstaat is looking for a way to benefit from the implementation of a life cycle costing strategy in maintenance and they want advice on the implementation of life cycle costing in maintenance. One specific example that Rijkswaterstaat wants to have examined is the strategy for the preservation of the lock gates. Should Rijkswaterstaat continue the present preservation or change to aluminizing of the gates, or? Chapter 7 contains more information on the maintenance costs of the preservation of the rolling gates. Rijkswaterstaat is also interested in one other example of your own choice that would support your advice to Rijkswaterstaat. The example of your choice has to be a major cost driver.
Of course, all decisions must be linked to the asset management objectives for this navigation lock. What is a good interpretation of the service level requirements? The SLA-PIN's as described in chapter 7 are not entirely clear. You need to pay attention to the performance requirement at corridor level and the contribution of the locks to this overall performance requirement. You will need to give a workable interpretation of the given SLA-PIN's.

## Background Information of the Case Hansweert

In chapter 7 a general description is given of the navigation locks at Hansweert:

- General Description
- Functions of the Locks
- Lock Construction
- Performance Requirements
- Maintenance

[1] SLA-PIN stands for Service Level Agreement (SLA) Performance Indicator (PIN)

More data on the navigation lock Hansweert is available on Brightspace. This information is of course not entirely complete to solve the above-mentioned problems, but it will be helpful. More and own research is necessary. On Brightspace you will find (source Rijkswaterstaat):

1. Design principles of lock gates in general (Rijkswaterstaat, 2000)
2. Drawings on the rolling gate operating mechanism;
3. A risk matrix in use at Rijkswaterstaat;
4. A complete system breakdown structure (SBS) of all objects of the navigation lock Hansweert;
5. A long-term maintenance planning (including major overhauls) on the rolling gates and operating mechanism and other essential components of the locks.

Like said, some of the data will be useful, some will not. And of course, some data will be lacking. It is the group's own responsibility to select the relevant data and find the missing data. In a real-life work environment, you will encounter unreliable data and missing data. It is your challenge to distinguish between useful and useless information and to make intelligent assumptions that are properly motivated.

> To assist the groups in the task, each group is allowed to ask for clarification after studying of the data and the problem descriptions. This needs be done in short writing and **all** groups will receive **all** questions and given answers. Do not be surprised if your client cannot or does not want to answer all your questions. After all, the client considers you as the knowledgeable consultant to provide the answers, not the questions. Do not risk your reputation (=grade) by bothering the client with questions that could be answered when studying the available material or with some additional research.

## Assessment Criteria - Case Study

Apart from studying the theoretical literature about the tool(s) and relevant information about the case from Brightspace, also look on the Internet and in the library, for relevant information about the case.
Your research should be done according to the general agreed criteria for good research and reporting.

> Remember, the general agreed criteria are: start with a problem statement, define a goal, design a research question, clarify the method of the research, explain the use of theory/concepts, give a clear presentation of findings, include a discussion and of course feedback to your own research question.

The case study report will be assessed based on the following criteria:
**Product**

- Standard requirements for reporting good research
    - As mentioned above
    - Proper use of an appendix
- Explanation of the main tool/method/technique in the case-specific context, this is meant to show your expertise:
    - Coverage of the topics - *an explanation of these topics will be given in one of the lectures.*
        - Definition, description of the tool;
        - A clear graph, illustrating, explaining the tool;
        - How to apply the tool and the limitations of the tool;
        - A small example of the application of the method in an asset management context. *This example has to be your own example, not an example copied and pasted from other sources. Make sure that your example is related to asset management and the case*
        - Reference to related and applicable NEN, EN, ISO or IEC standards
    - Use of own words in the assignment – it is tempting to copy/paste information from your sources – do not be tempted – see flyer on fraud/plagiarism on Brightspace.
- Description of the method of your case study
- Execution – data collection - of the method as mentioned
- Conclusion - answer to research question

- Recommendations for Rijkswaterstaat that are in line with findings
- Assumptions are explained

Process

- Well accepted standard or literature has been applied
- The application of the tool(s) is assessed against a chosen set of criteria – this links with the Methodology lecture
- Alternative tools are identified
- Limitation and short comings are mentioned and discussed – including the use of the main tool

Form

- Structure
- Language, spelling
- Layout, attractiveness
- Use of references

The assessment criteria of this assignment will be explained during one of the lectures and will be made available on Brightspace.

Learning objectives:

- Practicing the activity of underpinning the proper application of methods and techniques
- Negotiating your interests and objectives
- To be able to align goals, objectives and methods
- To be able to define a good research question
- Presenting the results of a case assignment in writing

## 5.4 Audit of the Case Study Report

After each group has handed in their case study you can start with the assessment/audit assignment. In this assignment, you will look at the asset management problem from a different angle. Each of you will individually *audit* one of the case study reports. This will of course be a case study report by one the groups you have not been part of.

The setting of the audit is as follows. A group has studied a given problem in the Hansweert case using an appropriate tool and has handed in a case study report. Consider Rijkswaterstaat the client of that report. Rijkswaterstaat wants extra certainty that the results of that report are good and that they can rely on the conclusions. Therefore, Rijkswaterstaat also demands that the case study report is accompanied by an independent audit report from a second knowledgeable expert (=you: the auditor).

The assignment to you, the auditor, is to answer the following question:

**- Can the client fully rely on the conclusions in the given case study report?**

In this audit report, you have to show that you are able to independently conduct an audit. As an introduction to the audit, two lectures will be given on auditing. Make sure that your audit is objective and underpin all your conclusions.

When preparing your audit, it is advisable that you carefully and early on identify the goal and criteria for your audit. In one of the lectures we will have a workshop where you can start the identification of the objectives and assertions.

It is important that you:

1. Show your *expertise* with a good description of the main tool/method/technique that is used in the case and its case specific application– see 5.2 for the items you should cover.
   Make sure that your description is linked to the application in the case study.
2. Explain (define) and explicitly motivate your choice of objectives, assertions, weightings, aspects, key criteria and their so-called SOLL-werts. Furthermore, one of the criteria of a good research or an audit

is *reproducibility*: make sure that your findings are well documented and that somebody else can conduct the same research.
3. Critically assess the strategy (line of reasoning and application of methods) that the group has followed to arrive at its conclusions.
4. Focus your audit on the content, the calculations, the data, the assumptions. For you, as an auditor the form (lay-out, style) is of lesser importance.
5. Include recommendations for improvement of the case study report. Make sure that the recommendations are in line with your audit findings.

Apart from studying the case study report, literature about the method(s) and relevant information about the case from the Internet and the library, you are also expected to interview at least two students that were involved in writing the case report to verify and possibly adjust your conclusions and recommendations.

## Assessment Criteria – Audit Report

The audit should be done according to the general agreed criteria for good research.

> Remember, the general agreed criteria are: start with a problem statement, define a goal, design a research question, clarify the method of the research, explain the use of theory/concepts, give a clear presentation of findings, include a discussion and of course feedback to your own research question.

The audit report will be assessed based on the following criteria:
**Content**

- Standard requirements for reporting good research
  - As mentioned above
  - Plus, an appendix including the framework and interviews
- Preparation
- Explanation of the main tool/method/technique in the case-specific context, this is meant to show your expertise:
    - Coverage of the topics - *an explanation of these topics will be given in one of the lectures.*
      - Definition, description of the tool;
      - A clear graph, illustrating, explaining the tool;
      - How to apply the tool and the limitations of the tool;
      - A small example of the application of the method in an asset management context. *This example has to be your own example, not an example copied and pasted from other sources. Make sure that your example is related to asset management and the case*
      - Reference to related and applicable NEN, EN, ISO or IEC standards
  - Use of own words in the assignment – it is tempting to copy/paste information from your sources – do not be tempted – see flyer on fraud/plagiarism on Brightspace.
  - Description of the method of your audit
  - Description and underpinning of objectives, assertions and aspects
  - Description and underpinning of materiality and weightings
  - Description of consultation of other auditors
  - Description and underpinning of SOLL werts
- Execution – data collection
  - Execution of the method as mentioned in the preparation
  - Well accepted standard or literature has been applied
  - Underpinning of the IST werts
  - Multiple audit techniques have been used and properly – including interviews
- Analysis
  - Difference between SOLL and IST is addressed
  - Root Cause Analysis for deficiencies and errors
  - Conclusion, answer to research question
  - Recommendations for Rijkswaterstaat and the authors of the case study report that are in line with findings

  - Remarks of group that was audited (interview)

    Interviews or transcripts that have no relation to the conclusion, recommendations or clarifications to the report may have a negative impact on the grading of your audit.

Form

- Structure
- Language, spelling
- Layout, attractiveness
- Use of references

The assessment criteria of this assignment will be explained during one of the lectures and will be made available on Brightspace.

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Learning objectives:

- To be able to conduct a (non-financial) audit
- To be able to reflect on somebody else's work and his/her (re)actions
- To be able to apply newly acquired knowledge on models/methods and techniques
- Presenting the results of an audit assignment in writing

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# 6 ASSESSMENT AND WEIGHTING

## 6.1 What Will Be Assessed?

The assessments of the group and individual assignments together will make up your final grade, see table 7. Your final grade is a weighted average of the assessments, provided you have passed the following conditions:

- The individual assignment has to be at least 6,0 and
- The grade of the group assignment has to be at least 6,0 and

If you do not pass the above conditions, see paragraph 6.2 What If?

Table 7 Calculation of Final Individual Grade

| | | | |
|---|---|---|---|
| **Group assessment** | 50% | Report of case study | |
| | | Timeliness of case study report | Correction* |
| **Individual assessment** | 50% | Report of audit | |
| | | Including description of method/technique | |
| | | Timeliness of audit report | Correction* |
| **Final individual score** | 100% | | |

> * Untimely handing in of the reports may lead to a correction of the grading. Time management, planning and sharing your workload are essential professional skills. This goes for the handing in of **both** reports. Timeliness of handing in the case report is especially important to facilitate progress of the following audit.

### Assessment Criteria

Details of the assessment criteria of the assignments are mentioned in chapter 4 and will be explained during the lectures.

## 6.2 What If?

You will not pass this course in case of the grading of:

- the individual assignment is < 6,0 or
- the group assignment is < 6,0 or

You have the opportunity to repair **one** of the assignments. The term for handing in the repaired assignment is **three weeks** after the feedback lecture. The date of the feedback lecture will be announced on Brightspace and will be held as soon as possible after the grades of all the assignments are available. The maximum grade after repair is 6,0.

# 7 NAVIGATION LOCKS AT HANSWEERT

The assignments are all related to the case: navigation locks at Hansweert. For general information on locks and their design, see Design of locks (Rijkswaterstaat, 2000) The most relevant chapter of this report is available on Brightspace.

Several videos of the navigation locks at Hansweert are available on Brightspace :

## 7.1 General Description

The navigation lock complex Hansweert is situated in the main transport link at the canal through Zuid-Beveland. This canal connects the estuaries of the Westerschelde and the Oosterschelde, running from Hansweert to Wemeldinge.


Figure 6 Location of the navigation lock Hansweert

The canal was originally built in 1865. In 1978 plans emerged to facilitate larger vessels such as pusher tugs with four barges. This resulted in the building of the navigation lock Hansweert. Hansweert consists of two locks with lock chamber dimensions of 24 x 280 meters (total length 314.6 meters). The building of the locks started in 1984. At the end of 1987 the Eastern lock was put in to operation, followed by the Western lock, early 1988. The Ministry of Infrastructure and Environment owns the locks and the government agency Rijkswaterstaat maintains and operates the navigation locks at Hansweert.

The canal has an open connection with the Oosterschelde. The locks at Hansweert are essential for separating the differences in tidal movements at the Westerschelde and the Oosterschelde. This gives the locks a dual primary function: lock passing and high water protection.

In the early nineties, the canal was upgraded in accordance with the increasing shipping demands. In September 1993, the improved canal was put into service. The dimensions (cross section) of the canal and the locks at Hansweert are designed for river Rhine navigation and pusher tugs with four barges – CEMT class VIb, a standard class for inland shipping. This makes the navigation route passing Hansweert suitable for vessels with a maximum length of 195m, a maximum width of 22.8m and a maximum draught of 4.5m. The width of canal allows for three shipping lanes at low tidal water.  All bridges crossing the canal are movable bridges, resulting in no restrictions for the height of the vessels. The clearance for the fixed parts of the bridges is 9.10 meters at a water level of + 1.50 mNAP.

At both sides of the canal, guide-pilings and waiting-berths have been realized. Each year about 44.000 vessels pass the locks, including almost 7.000 recreational vessels.

Table 8 Characteristics of navigation locks at Hansweert

| Item | Description |
|---|---|
| Object Name | Navigation Lock Hansweert |
| Top coordinates | RDX = 59.294, RDY = 386.09 |
| Object Type | (Pusher tugs) locks |
| Object Code | 48H-353 |
| Put into operation | 1987 / 1988 |
| Functions | Lock passing<br>High water protection<br>Crossing of land traffic |
| Number of lock chambers | 2 |

## 7.2 Function of the Locks

### Primary Function: High Water Protection

Tidal water is situated at both the north and south side of the lock complex Hansweert. The lock complex is part of the primary high water protection of the Westerschelde and the Oosterschelde. Safety level rates (probability of exceeding of limits) for primary and secondary high water protections are legally bound and set at 1/4000 per year for the Westerschelde and the Oosterschelde. The high-water protection function trumps the interest of other functions.

### Primary Function: Lock Passing

The shipping corridor Hansweert - Krammer is a main transport axis. The primary function of navigation lock Hansweert is the locking of ships to overcome the differences in tidal water between the Westerschelde and the canal though Zuid-Beveland. Shipping transport takes place 24 hours a day and 7 days in a week. The lock complex Hansweert is a conventional lock system that levels water before and behind the lock. Passing of vessels should be fast and safe.

### Secondary Function: Crossing of Land Traffic

Motorcyclists, cyclists, pedestrians and destination traffic can pass the lock across the rolling gates and the lock island. The passage is also suitable for accidental use by emergency and service vehicles.

## 7.3 Lock Construction

### The Lock Chambers

The lock complex Hansweert consists of two parallel lock chambers with each a width of 24m and length of 280m. The base of the lock chamber (lock still) is located at -7.30m NAP.

Each of the two locks includes a lock chamber and two lock heads. The lock walls consist of a steel sheet piling, concrete foundation piles and an L-shape concrete wall. The base floor between the walls is constructed of poured underwater concrete. Each lock head consists of a gate chamber and a gate recess, which allows for a horizontal roller gate.

A central operation and control building is situated between the two lock chambers at the lock island. Several technical buildings are located at the lock island as well, near the lock heads. The technical buildings contain the electromechanical installations for operation of the rolling gates.

Table 9 Lock characteristics

| Description | Dimensions |
|---|---|
| Lock length | 280 m |
| Lock width | 24 m |
| Still level (lock depth) | –7,30 mNAP |
| Level of capstone lock chambers | +7,00 mNAP |
| Dimensions of rolling gates (w x h x d) | 27,8 m x 14,6 m x 4,69 m |
| Operation of locks | Continuous |
| Ship passages per year (2012) | Inland navigation: 43559<br>Recreation: 6841<br>Sea navigation: 333 |

## The Lock Gates and Operating Mechanism

The lock chambers take in salt water and are locked with the rolling gates positioned at the lock heads. The rolling gates are opened and closed up to 45 times a day. Gate chambers and gate recesses allow for movement, closing, opening and storage of the gates. The rolling gates have operating mechanisms in the shape of cable winch gear that opens and shuts the gates. The cable winch gears are positioned in separate rooms at the backside of the rolling gate chambers. The axis of the gearbox is connected with a cable drum. The cable drum drives the upper scrollwork, which is clutched with the rolling gate. The rolling gates are provided with each two lower roller carriages that move along a rail positioned at the bottom of the lock chamber entrances (see figures 7, 8, 9, and 10).

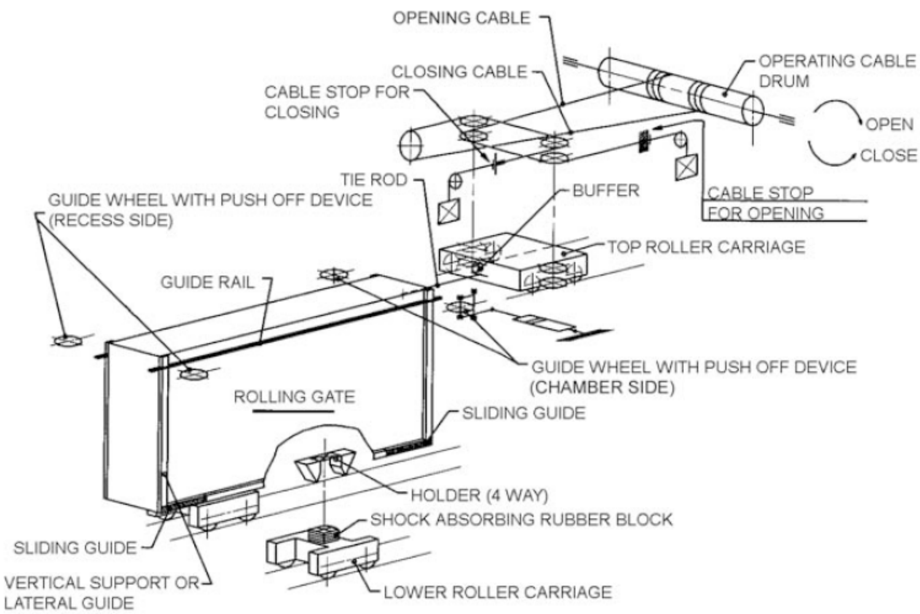


Figure 7 Rolling gate operating mechanism (source: Rijkswaterstaat)

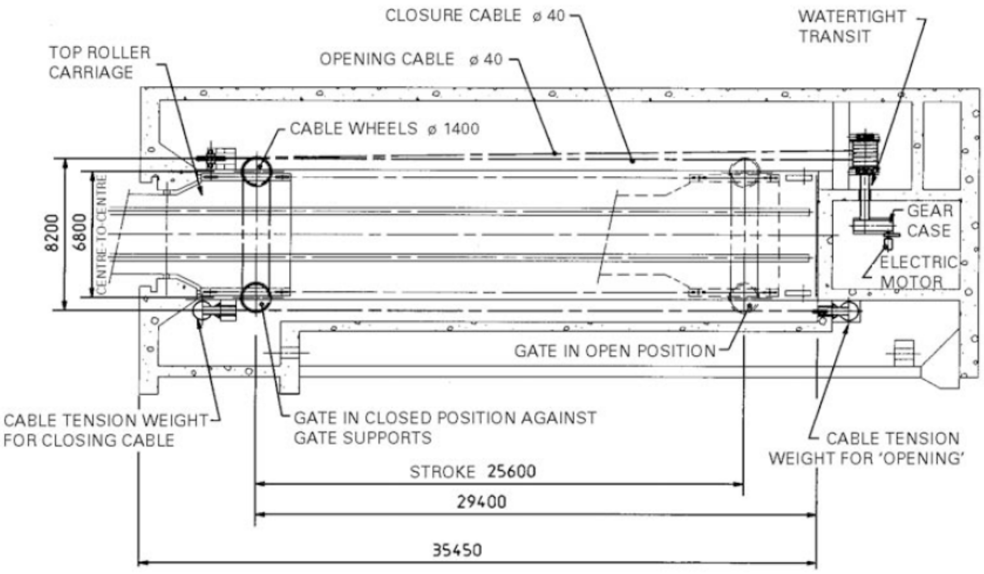


Figure 8 Rolling gate with two-sided operating mechanism and single cable drum (source: Rijkswaterstaat)

Figure 9 Lower roller carriage with two of the guiding wheels visible (source: Rijkswaterstaat

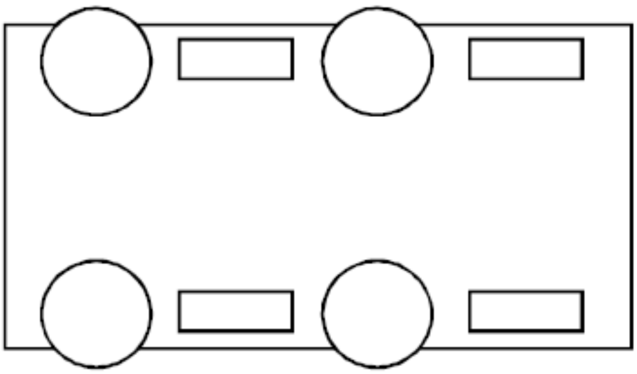

Figure 10 Principle diagram of a lower roller carriage seen from above with guiding wheels and running wheels (source Rijkswaterstaat)

A hydraulic drive mechanism provides for fixation of the rolling gate in closed position. Each gate weighs as much as a Boeing 747. The speed of the rolling gate is regulated electromechanically in a redundant configuration. In case of breakdown an emergency transition motor is called upon. In that case the operating speed of the gate will be reduced. The control installation of the rolling gates is situated in local buildings at both lock heads.

The rolling gates are accessible for local traffic. Each rolling gate is equipped with stop signs and barriers.

### Lock Paddles or Levelling Gates

Each rolling gate has five levelling openings, which are equipped with lock paddles (levelling gates). The lock paddles are electromechanically driven and move vertically. The lock paddles are used for levelling the water at both sides of the gates. The lock paddles are provided with detection equipment for open and closed positions. At least two lock paddles per gate are required for proper functioning of the lock.

### Level Measurement

Water levels are measured with a level measure installation that consists of measuring pipes, pressure gauges, compressors and recording equipment. These are located in the cellars of the lock heads.

### Emergency Generator System

Under normal condition power to locks is provided through the national electricity grid. In case of a power failure emergency power is provided by means of two diesel generators. The emergency power generation system is situated in the electro-technical building on the lock complex.

### Buildings

Several rooms are located at the lock heads among which the cellars, the rolling gate chambers and gate recesses. At the lock island houses: the central control building, the building for electro-technical installations, the compressor building and a second not in use service building that still contains glass fibre connections.
The original design of the navigation lock provided for air bubble screens to prevent polluted water from the Westerschelde to enter the lock chambers in open position. Over time the water quality of the Westerschelde has improved significantly, making the planned air bubble screens and compressors obsolete. The name of the compressor building, however, did not change. There are no compressors available in this building.

### Fire Extinguishing System

The fire extinguishing system supplies (salt) water through fire hydrants and a system of fire mains. Three mains are available, one each at the outside of the north and south lock chambers and one in the middle. The water is taken in by pumps located at both lock heads at the canal site of the lock complex. Each pump is individually deployable at all fire mains. The operation of the pumps is located in the central control building.

## 7.4 Performance Requirements

Every four years a Service Level Agreement (SLA) is agreed upon between the Ministry of Infrastructure and Environment and Rijkswaterstaat. The SLA contains Performance Level Indicators (PIN's). The SLA and PIN's are translated into so-called Management Contracts between the general board of Rijkswaterstaat and each of regions of Rijkswaterstaat – this will be explained in one of the lectures. These regions are responsible for operating and maintaining the assets within their region. The region of Zee & Delta is responsible for the locks at Hansweert. Additional performance requirements follow from legal regulation, like the National Water Act.

## Performance Requirement: High Water Protection

Performance requirements for the primary function high water protection are mainly obtained from the National Water Act and related directives such as the decree on safety assessment 2006 (VTV 2006) and the so-called *hydraulic boundary conditions* (HR 2006).

The Water Act prescribes a five-yearly assessment of primary high water protection on safety (strength, height, stability, etc.). The navigation lock Hansweert connects two primary high water protection systems and therefore classifies for the highest level of safety assessments. Hansweert is classified as a 'connecting high water protection class b.' Maintenance of the primary high water protections (with exception of navigation lock Hansweert) is done by the local Water Board.

The legal function requirement for high water protection is to comply with the five yearly assessments prescribed by the National Water Act.

Additionally, the RWS management contract contains a required performance level for primary high water protection (a PIN) based on a status-quo principle as a minimum. The high-water protection function of a primary high water protection should remain at least at a base level set in 2011.


Figure 11 Location of primary high water protection at navigation lock Hansweert

## Performance Requirement: Lock Passing

In the Rijkswaterstaat management contract for main shipping routes, several performance indicators (PIN) are set in that are relevant for navigation lock Hansweert. Three of these PIN's are derived from the national service level agreements PIN's:

- SLA-PIN 1: Planned downtime for navigation shipping
- SLA-PIN 2: Technical availability for the corridor
- SLA-PIN 3: Unplanned downtime for navigation shipping
- SLA-PIN 4: Lock Passage Time

The underlying philosophy for each of the PIN's is that hindrance to navigation shipping should be kept to a minimum.

## SLA-PIN 1: Planned Downtime for Navigation Shipping

The unavailability caused by planned maintenance on lock complex is limited to a maximum of 0,8% per year of the operating service hours. All planned maintenance is communicated in advanced and fine-tuned with relevant stakeholders on the entire shipping route. For navigation lock Hansweert, SLA-PIN 1 results in a requirement of a maximum of planned downtime of 70 hours per year for the entire lock system. Downtime starts a soon as the locks are not available for the standard size vessels.

At present, downtime caused by planned maintenance is registered in two data systems: the NIS and the OMS. This is not an ideal situation and should be improved. Planned maintenance should be reported in the *Planning for national maintenance navigation routes*. The minimum time of planned maintenance is one hour. In case of maintenance work exceeding a year boundary, the downtime of the maintenance work is proportionally divided among the years.

## 3.4.2 SLA-PIN 2: Technical Availability Corridor

The unavailability caused by both planned and unplanned maintenance on the shipping route is limited to 1,0% per year of the operating service hours. This PIN focuses on the availability of the shipping route that includes the navigation lock Hansweert, several movable bridges and the shipping lanes. At present the contribution of the shipping lanes to the availability of the corridor is set to 100%. So practically the PIN relates to the locks and the movable bridges, not to the shipping lanes.
There are three bridges crossing the corridor:
1. Postbrug – road; 2. Vlakebrug – road; 3. Vlakebrug – rail
The Postbrug and Vlakebrug – roads are maintained and operated by Rijkswaterstaat. The Vlakebrug is maintained and operated by ProRail.

## SLA-PIN 3 – Unplanned Downtime

The unavailability caused by unplanned maintenance activities and technical failures on the locks at Hansweert is limited to 0,2% per year of the operating service hours. This comes down to 17,5 hours per year for entire lock system at Hansweert.
Unplanned downtime starts a soon as the locks are, unexpectedly, no longer available for the standard size vessels.

Downtime caused by unexpected technical and operational failures is registered in two data systems: the NIS and the Infor EAM system. Again, this is not an ideal situation and should be improved.

## SLA-PIN 4 - Lock Passage Time

A fourth PIN is the lock passage time. An important factor for the shipping industry is the reliability of their journey times. This includes a reliable passage time for the locks within their shipping route. The service level for achieving the agreed passage time at Hansweert is that 72% of the vessels passing the locks should do so within the agreed passage time. In the first half of 2015 the performance of the locks on this indicator was 83%. This indicator heavily relies on the availability of both lock chambers.

# 7.5 Maintenance

### Preventive and Condition Based Maintenance

Preventive (time or run-time based) and condition based maintenance is carried out periodically among which:

- Daily and monthly visual inspections;
- Preventive and predictive maintenance on (electro)mechanical equipment;
- Preventive and predictive maintenance on civil works;
- Testing of auxiliary equipment;
- Water bed depth measurements;
- Cleaning.

## Corrective Maintenance

Corrective maintenance (repairs) is classified in urgent and not urgent and is planned for repair accordingly. Urgent failures are failures that cause an unsafe situation or immediate unavailability of one of the lock chambers. Examples of urgent failures are:

- Rolling gates that do not open or close properly (whatever reason);
- Levelling gates that do not open or close properly (whatever reason);
- Visual and communication systems that do not function properly;
- Safety barriers or navigation lights that do not function properly.

## Major Maintenance / Overhaul (Rolling Gates)

At the moment, every twelve years major maintenance is carried out on the rolling gates and lower rolling carriages. The rolling gates are completely taken out, preserved and electro-mechanical overhauls or even modifications (revisions) are carried out.

The twelve-year period is based on the routine and historical maintenance of the critical parts of the gates, being the preservation of the steel frame and lower rolling carriages. Recently, RWS was unpleasantly surprised by two failures of the rolling gates resulting in unplanned downtime for one of the lock chambers. Bearing failures of the lower roller carriages caused the downtime. One of the two failures resulted in a one-month downtime. On the other hand, there have been twelve-year periodical door overhauls in which nothing proved to be wrong with the lower roller carriages bearings.

The lock gates need to be preserved next year. The present preservation of the lock gates consists of an epoxy primer with an expected functional mean life of 18 to 24 years based on whether or service life extending maintenance has been carried out. Service life extending maintenance is limited to local restoration of the coating every 12 year years and is combined with other maintenance work on the rolling gates. Leaving out service life extending maintenance will result in an expected lifetime of the preservation of 18 years. Service life extending maintenance will extend the lifetime of the coating 12 years after this maintenance is done. Therefore, major maintenance is on average conducted every 18 to 24 years and consists of blast cleaning to SA 2.5 and full renewal of the coating. Based on experience with navigation locks, Rijkswaterstaat assumes a normal probability density function with a standard deviation of 2 years for both mentioned functional mean lives
An alternative to epoxy coating is to *aluminize* the gates, which will prolong the functional lifetime of the preservation to an expected 50 years, following a normal probability density function with a standard deviation of 3 years, according to suppliers. No service life extending maintenance is required, again, according to suppliers. RWS has no experience with aluminizing. For an indication of the costs of the maintenance of the preservation see table 10. The surface area of one rolling gate is 3000 $m^2$.

Table 10 Cost indicator for preservation of the rolling gates

| Description | Unit costs |
|---|---|
| Local restoration | € 30 / $m^2$ |
| Blast cleaning | € 25 / $m^2$ |
| Regular preservation | € 40 / $m^2$ |
| Aluminisation | € 95 / $m^2$ |

# 8 LONG LIST OF METHODS AND TECHNIQUES

On top of the methods and techniques that were explained in the lectures, there is a long list of tools, instruments, models, methods and techniques that are used in asset management decision-making. For some of them references are included:

1. Failure Mode and Effects Analysis (FMEA)
2. Failure Mode, Effects and Criticality Analysis (FMECA)
3. Fault Tree Analysis (FTA)
4. Life Cycle Costing (LCC)
5. Reliability Centred Maintenance (RCM)
6. Risk Analysis (RA)
7. Risk Management (RM) (Osborne, 1997)
8. Reliability, Availability, Maintainability, Safety (RAMS)
9. Lean Management (LM)
10. Scenario Planning (SP)
11. Mapping out responsibilities and authorities in teams, who is responsible, accountable, supportive, consulting, informing (RASCI)
12. Performance Management (PM)
13. Service Level Agreement/Service Level Management (SLA/SLM)
14. Stakeholder Analysis/Stakeholder Management (SA/SM) (Bourne, 2010; Gilmour, 2006; Wheeler, 1997)
15. Balanced Score Card (BSC) (http://www.balancedscorecard.org; R. S. Kaplan, & D.P. Norton, 1993)
16. Ishikawa Diagram
17. Value (Based) Management (VM) (Copeland, 1990; Stewart, 1991)
18. Function Analysis System Technique (FAST)
19. Best Value Procurement (BVP)
20. Costs-Benefits Analysis: Financial justification of projects/investments
21. Strategy Map: The translation from strategy to measurable indicators
22. Activity Based Costing: Assigning costs to the activities that incur them. (R. Kaplan, Anderson, S., 2007; R. S. C. Kaplan, R., 1998)
23. Decision Table/Multi Criteria Analysis: Making considered choices from different options
24. Six Sigma: Quality and process improvement (Pries, 2007; Snee, 2009)
25. Supplier Selection: Selecting the most suitable supplier(s) (Garfamy, 2009; Sonmez, 2006)
26. SWOT: Establishing strengths and weaknesses of the enterprise and the opportunities and threats. (Ferrel, 2009; Fine, 2009; Hunger, 1998)
27. BCG Matrix: Portfolio analysis (Henderson, 1979; http://bcgmatrix.org/)
28. Kraljic Matrix: Portfolio analysis for purchasing (Bohlin, 2008; Kralic, 1983; Kraljic, 1983)
29. Resource Based View: Adequate deployment of available resources (J. Barney, 1991; J. Barney, Clark, D., 2007; Wernerfelt, 1984)
30. Core Competence (Gorter, 1994; G. Hamel, Prahalad, C., 1990, 1994; G. P. Hamel, C.K., 1995)
31. Kaizen (Imai, 1994)

Generic:

32. Benchmarking (http://www.hutchins.co.uk/Ar_Bench.aspx; Verwey, 1997)
33. INK/EFQM (T. W. Hardjono, Have, S. ten, Have, W.D. ten, 1996; T. W. Hardjono, Hes, F.W., 1994; www.efqm.org)
34. Risk-based Operations and (van den Boogaard & van Akkeren, 2011, 2012)

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