# Application of Value Methodology to Improve Preservation of Infrastructural Assets in Rijkswaterstaat

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# Preface

This report has been written as part of the MSc programme of the section Design and Construction Processes at the faculty of Civil Engineering and Geosciences of Delft University of Technology. The project is supported by Grontmij and based on a PIM project (Partnerprogramme Infrastructure Management) in Zeeland, where Grontmij works as one of the partners of Rijkswaterstaat. The application of Value Methodology in preservation phase of infrastructure assets has been investigated during a period of nine months.

I am very glad that Grontmij provides me with the opportunity to work on such an interesting project. Rijkswaterstaat is experiencing a significant evolution in its way of working and thinking. By applying asset management, Rijkswaterstaat is trying to become a customer oriented asset manager and a service provider. As many ideas are new in the PIM project, a lot of questions rise, which brings a lot of challenges. As a master student, I feel excited whenever I find that my work may have some contribution to the changing process of Rijkswaterstaat, no matter how much it is. I have to say, it is my great experience to do my thesis work with help of people from both Grontmij and Rijkswaterstaat. This precious opportunity enables me to find a way to integrate theory with practical aspects and learn many things besides academics which cannot be obtained from textbooks.

This thesis research could not be accomplished without the help of supervisors, colleagues, friends and family. There are many people I would like to thank.

My gratitude first goes to the colleagues from Grontmij who have provided any help and support I need for research. I would like to extend my heartfelt thanks to my daily supervisor Dr. Frits Willems for his great help during this project, for his patience, readiness to support and face-to-face meetings every week. Special thanks go to Peter Vermey who recommended and supported a trip to UK which greatly enriched my experience and knowledge, and also to Dennis Vlassenrood who is the contact person between Grontmij and Rijkswaterstaat and always ready to help me.

I have to say, thanks to all the nice and helpful people in Rijkswaterstaat ‘s Heer Arendskerke and Middleburg, my days there were very fruitful. They gave me three times of guidance to the locks. They tried their best to speak to me in English and somebody read my report and tried to help me even when he was ill at home. They are also very knowledgeable and patient to tell me whatever technical aspects I would like to know. I do not think any word can express my gratefulness to them.

Moreover, I would like to thank all the committee members at the universities who have supported me and taught me the academical level of research patiently. Many thanks go to the chairman of the committee, Prof. de Ridder; another professor from Aerospace faculty Prof. Smit; part time lecturer of TU Delft but also experienced manager in Rijkswaterstaat, Leon Hombergen; and Andreas Hartmann, lecturer from University of Twente and a really good researcher.

A lot of thanks go to my good friends Ahero, Eline and Zony, for their help with the reporting and research methods discussions. Also thanks to all my friends who shared memorable moments with me during the last two years’ study in the Netherlands.

Last but not least, I would like to thank my family especially my great parents who have provided me such a colorful life and have been supporting me all the time.

Thank you all.

Delft, September 2008
Xiaowei Li

## Summary

Dutch public service providers like Rijkswaterstaat and ProRail contract major part of the maintenance out. The government expects Rijkswaterstaat and ProRail to grow in their role as asset managers. Rijkswaterstaat wants to decrease the cost of maintenance by contracting out network maintenance by means of a Service Provider Contract within which better maintenance strategies are stimulated from the market. A contractor will take charge of all maintenance activities of a network also including maintenance plans and improvement change proposals, which will be a challenge. The problem is how to identify maintenance improvements and demonstrate to Rijkswaterstaat that they represent best value for money; for Rijkswaterstaat, the main problem is how to evaluate these improvement projects and make decisions.

Value Methodology (VM) is proposed by Dr. Frits Willems from Grontmij, as a possible way to help solve the problems. VM is a strong problem-analyzing and decision-making tool which matches the problem framework. Besides, based on an insight of its development and applications in other Government agencies, and comparisons with other relative methods, a conclusion is drawn that it is worthwhile researching on VM to see how it can help. VM is the starting point of this thesis research. The objective is to develop a framework of the application of Value Methodology, in order to identify maintenance improvements on infrastructural assets and guide decision-making on renewal and modification projects.

An infrastructure asset (Hansweert Locks) is chosen as the case study. It follows a detailed VM approach developed from literature study and VM applications in ProRail and British Highways Agency. The case study mainly focuses on the first four phases of VM including information phase, function phase, creative phase and evaluation phase. The whole process receives a lot of support from Rijkswaterstaat employees including infra-provider advisors, technical people in civil, electrical and mechanical disciplines, an operator and a traffic manager. The author works as the value engineer. The information phase with an introductory meeting and interviews makes a good preparation for the workshop session; the workshop during function phase plays a crucial role on identifying project problems and clients' demands, and results in identification of ten critical functions; group discussions during creative phase develop more insight of the critical functions and several improvement alternatives; and the last phase proposes a decision-making framework based on the client's value system.

Following a proposed Value Methodology approach, the four-month case study on Hansweert Locks has brought fruitful results. However, the process also comes across many difficulties, mainly because of language obstacle, lack of information and the traditional culture of Rijkswaterstaat. To solve these problems, an improved VM approach is presented after the case study, as shown in the figure on the following page.

A successful implementation of this approach requires several conditions. Only when these criteria are achieved can a good and effective value study be carried out within Rijkswaterstaat.

- **Team cooperation.** A good value study depends much on enough cooperation from the whole team. To stimulate maximum team effort, three key factors are demanded: enough support from management level; good communication between value engineer and team members; and a multi-skilled workshop facilitator to encourage expressions of ideas.

- **Information.** The case study recommends the collection of a list of information that should be present before workshops in value studies of maintenance improvement projects.

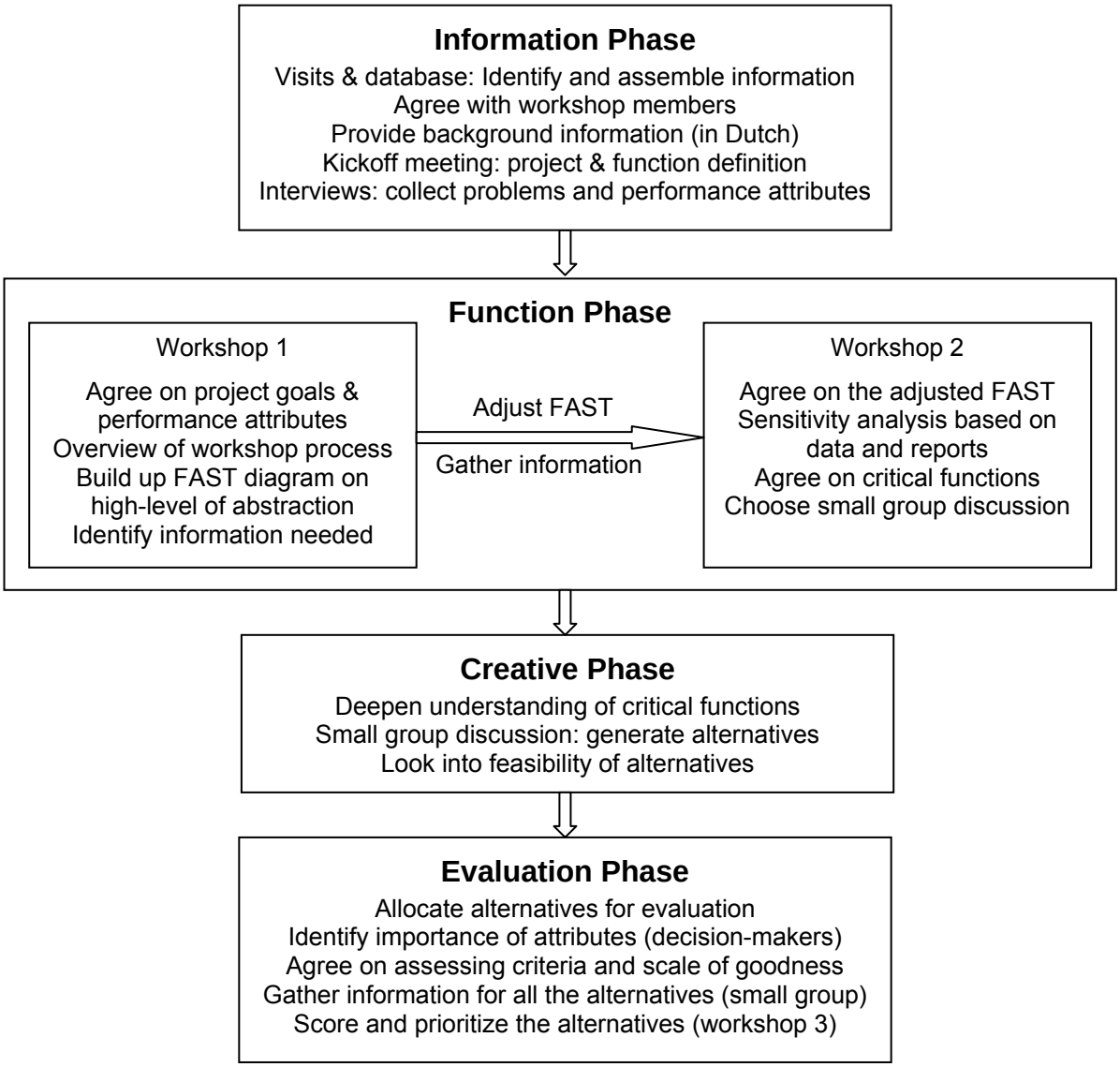
  Maintenance historical data about:

  - All technical failures and accidents due to technical problems in the last two to three years which have impact on the availability and ship passing time of the waterway. Allocating the causes to each sub-system; collecting the data of the downtime, delay hours, number of delayed ships and consequence of accidents, Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR);
  - All maintenance costs on those sub-systems which break down quite often;
  - A safety report and an environment assessment report of the current situation;
  - A survey of customer satisfaction.

About maintenance improvement projects (renewals and modifications):

- Investment cost of the project, life span of the new system and depreciation rate;
- Annual maintenance cost of the new system, maintenance cost on other parts which will be influenced by the project;
- Failure rate, MTBF, MTTR of the new system;
- Environment assessment report or other documents showing environmental factors have been considered in the project.

- **"Stick to the facts" attitude.** In a good value study, each choice during the process should be made according to data and facts instead of experience or intuition only. Although experience is rather important, a good decision should base on supported facts. People in Rijkswaterstaat trust on others' experience so much that little challenge is given on gut feeling. "Stick to the facts" attitude should be emphasized.




The case study shows a lot of benefits from application of VM which include: constructive way of identifying improvements during preservation phase of an infrastructure asset; adequate decision-making framework for evaluation of maintenance investment alternatives; communication platform for Rijkswaterstaat and the contractors; and pinpointing out required information. As a result, if the improved approach and the success factors are followed, Value Methodology can be well implemented and will be useful for Rijkswaterstaat and future contractors in identifying and making decisions on maintenance improvements.

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# 1 Introduction

This chapter starts with background information of this thesis, and problems are derived. To solve the problems, a method (Value Methodology) is proposed, as the starting point of the research. This choice is based on the benefits of applying VM and comparison with other methods or tools. Well defined research objectives and questions are then listed, which should be verified and answered in the last chapter of this report. The last parts of this chapter introduce the working method, layout of the report.

## 1.1 Rijkswaterstaat and PIM Projects

### 1.1.1 Rijkswaterstaat and Its Way of Outsourcing in Maintenance

Rijkswaterstaat, founded in 1798, is part of the Dutch Ministry of Transportation and Water Management. This agency takes charge in the practical execution of the so-called waterstaat, which includes the construction of waterways and roads and their maintenance. This agency not only works on the protection against floods and ensuring that there is sufficient clean water for all users, but also provides smooth, safe flow of traffic on the country's roads and waterways.

Rijkswaterstaat has 9,000 employees who work at 240 locations. The organization consists of a head office accommodating the management and staff, ten regional services, five national services and three project management departments. These three project management departments are HSL-South, Maas Works and Room for the River.[1]

For years, Rijkswaterstaat contracts major part of the network maintenance out by means of traditional contract with detailed specifications. A range of maintenance contracts, often discipline-based and usually concluded with different parties, set out agreements on the maintenance of the major road and waterway networks, engineering works and route, and technical installations. Maintenance plans are made by Rijkswaterstaat himself according to the basic level of maintenance and the works are outsourced to contractors who offer lowest prices. The basic level of maintenance is defined as follows[2]:

*The basic maintenance level shows which minimum package of measures is necessary in the area of management and maintenance to maintain the present infrastructure in both physical and functional respect under prevailing conditions in the longer term, based on the service levels for users agreed by the principal and the standards and guidelines for the carrying out of maintenance.*

However, the Dutch Ministry of Transportation and Water Management is not satisfied with the poor service level of the infrastructure in recently years. The ministry admitted that too little was invested in the maintenance of roads, rails and waterways in the past, which had resulted in more frequent congestion on the roads and damage from loose chippings, shippers being unable to continue their journey due to faulty bridges/locks and train passenger delays due to defective overhead wires, signs and switches. For this reason, maintenance has been given top priority. In the coming years, Rijkswaterstaat will be investing in the construction and maintenance of Dutch roads and waterways[1].

**The objective of Rijkswaterstaat is to improve the value of their infrastructure assets. As expected by the ministry, the strategy of Rijkswaterstaat is to grow their role as an asset manager.**

### 1.1.2 Partner Programme for Infrastructure Management

Partner Programme for Infrastructure Management (PIM) started with the background described in the last section. It is a partnership between Rijkswaterstaat, British Highways Agency, Flemish Infrastructure Agency, and two private consultancies, Atkins and Grontmij. The final aim of PIM is better, more intelligent maintenance of the highways and waterways, and a faster traffic flow. Taxpayers will get better value for their money; the clients of Rijkswaterstaat (i.e. all members of the

[1] Sources: *http://www.verkeerenwaterstaat.nl*
[2] Reference: *Basic level of maintenance of the network of main roads in the Netherlands*, Rijkswaterstaat, 2002

public) will be more satisfied. And the people, who carry out maintenance or highway management on a professional basis, can do a better job.[3]

In 2006, four pilots have been selected across a nationwide spread. They are briefly introduced below. (www.projectpim.nl)

- **Road Stewards Pilot:** Although their main aim is a fast, safe traffic flow, road stewards spend a lot of time on road management, a task that could easily be organized more efficiently. The Road Stewards pilot that PIM has set up in the Zwolle roads district gives road stewards the opportunity to have input into improvements in their work processes. During a working visit to England the road stewards picked up a lot of good ideas that have been adapted to Dutch conditions and tested in this pilot;
- **Traffic Management Pilot:** The basic principle of traffic management is to cause as little inconvenience as possible to road users by improving work processes. The Traffic Management pilot is taking place at the North-west Netherlands Traffic Control Centre in Velsen. The aim of the pilot is to put the road user centre-stage when traffic management measures are put in place. PIM gives the control centre space to experiment and to deviate from current methods, which the centre sees as a unique opportunity.
- **Asset Management Pilot:** The Asset Management pilot in the Haaglanden and Rijnmond road districts is designed to answer the question how asset management can be used to improve the systematic management and maintenance of main roads. The pilot is taking place in the Haaglanden and Rijnmond road districts. The trial area is the A13 motorway between The Hague and Rotterdam. The pilot focuses on the physical infrastructure of the main roads, in this case the pavements, civil engineering structures and dynamic traffic management systems (DVM). This involves Rijkswaterstaat looking at the equipment in use, the manpower available and its operational processes. The information available on infrastructure is also important, as are the applications Rijkswaterstaat uses to manage this information.
- **Network Contracts Pilot:** The changes to integrated maintenance procurement and tendering move fast in Rijkswaterstaat Zeeland. PIM's Network Contracts pilot (also known as the Network-oriented Procurement pilot) is dramatically changing the way work is put on the market. The pilot consists of two experiments with network contracts. On the civil engineering side, there is an innovative contract for the maintenance of all major roads in the Zeeland regional directorate. On the hydraulic engineering side, a network contract is being developed for an entire waterway route.

As this thesis research is based on the background of the hydraulic engineering part of the Network Contracts Pilot, more introductions is given next.

Comparing to the traditional way of outsourcing, Rijkswaterstaat Zeeland is moving to a single contract per network with a single supplier, with a private party also coordinating implementation in the Network pilot. By means of a Service Provider Contract (SPC), Rijkswaterstaat aims at motivating the market to introduce better maintenance strategies and decreasing the maintenance cost. The emphasis of a SPC is not only on objects but also on the functioning of the road or waterway as a whole; not only on technical problem but also on terms of safety and traffic flow. This 'Service' idea is in line with Rijkswaterstaat's vision for the future but challenges the way of thinking from both Rijkswaterstaat and contractors.

In the hydraulic engineering part of PIM project in Zeeland, which is called Network Hansweert-Krammersluizen (NHK) project, Rijkswaterstaat was going to outsource the maintenance of the whole waterway, which includes three locks, two bridges and one traffic centre, to one contractor instead of thirty contracts to a range of contractors.

This contract is full of innovations. The private party is helping to develop a possible bonus/penalty scheme. In fact the pilot participants are not just involved in maintenance; they are also formulating a new type of contract, working with one contract rather than a whole series, and managing everything based on performance and functional quality requirements rather than separate activities. Even at the outset, the contract contains a significant number of items not found in traditional contracts, including the fault repair service, the coordination of contracts for work carried out by third parties, and the description and management of area information in a maintenance management system.

[3] General introduction of PIM and the pilot projects are from the website: *www.projectpim.nl*

What is more encouraging, the pilot is also developing a new strategy for management and maintenance. This is possible because a renovation provision is also included in the contract. Moreover, the contractor will be able to submit proposals for improvements and/or renovations that are in keeping with the waterway's function.

According to the NHK project workshop within Rijkswaterstaat, the objectives of this project are:

- Improve the service to the users by thinking and acting along the corridor system;
- Improve the added value in the supply chain by outsourcing at a higher level;
- Improve processes and make them transparent, to enable the successful transition of Rijkswaterstaat into an output oriented governmental agency;
- To demonstrate the added value of Rijkswaterstaat to the stakeholders.

At the end of 2007 when this thesis research started, the project was on tendering phase. The contractor was chosen in June 2008 and the EDC (Effective Date of Contract) is on 1st October 2008. Within a few months, the contractor and its subcontractors will be busy with the maintenance management system and their change proposals (wijzigingsvoorstel) about maintenance improvements or renovations of the waterway.

## 1.2 Problem Statement

In the conventional way of working, Rijkswaterstaat made maintenance plans and asked contractors to carry out one part of them according to detailed task specifications. What is totally different in performance based network contracts[4], contractors are going to take charge of the maintenance of the network, covering both electrical and mechanical installations and also civil part in future. This work includes tasks of making maintenance program, proposing improvements and/or renovations, planning and carrying out maintenance activities.

When the contractor gets the black box of maintenance for the whole waterway, he might think about three aspects of improvements in order to improve the work and win the incentives, thus to create more profit:

- Make present maintenance activities more efficient; As the maintenance work was carried out by different contractors in different disciplines, the new contractor might think about integration of all maintenance activities to reduce disruption and save cost.
- Improve the maintenance program which plans all preventive maintenance tasks; Methods like Reliability Centered Maintenance, which aims at managing the risks of equipment failure most effectively, should be considered.
- Renewals of some installations in order to achieve lower maintenance cost or higher performance; Installations for the waterway structures especially electrical and some mechanical parts are very old fashioned. On one hand, they cause failure frequently during recent years and thus more disruption of the traffic and maintenance cost. On the other hand, they cannot talk with new installations with new technology and does not fit for future. According to the strategy of Rijkswaterstaat mentioned in section 1.1.1, extra funds have been made available to deal with the maintenance backlog of waterways. Thus proposals for renewals are highlighted in the NHK contract.

The different way of working introduces problems for both Rijkswaterstaat and contractors, which this thesis research aims at:

- Contractors: According to the new way of thinking and working analyzed above, the problem for contractors is: how to look at the black box of maintenance and identify improvements to reach optimum cost effectiveness on the maintenance of infrastructure assets?
- Rijkswaterstaat: In the near future, the contractor will submit their maintenance change proposals including renewal and modification projects, but there is no efficient way of decision-making for Rijkswaterstaat at the moment.

[4] In these contracts, Performance Indicators of the technical system are measured as a basis for payments.

## 1.3 Proposed Method – Value Methodology

To be a conclusion of the above problem statements, a problem-analyzing method with decision-making tools should be developed. Value Methodology[5] (VM), in this situation, is proposed by Dr. Frits Willems from Grontmij, as a possible method to help solve the problems. Three significant advantages of VM match the problems and provide solutions:

- Value Methodology is a structured problem solving method based on function analysis. Function model of a product or service is built up and functions are examined then by a list of important attributes and cost sorts. The key approach is that when critical functions (performance killers and cost drivers) are pinpointed, efforts can be put only on those functions, which provides the highest cost efficiency improvement. This process provides a way of problem analyzing from function point of view by asking and answering questions "why the system and subsystems exist?", "which functions have significant contributions to our important value attributes?" and "What else can perform the same function with better results?"
- Value Methodology derives a value system for clients or stakeholders based on which all alternative solutions are evaluated and compared. This value system, which includes a list of attributes and relative importance, not only guides function analysis but also helps with decision-making process. As a result, one of the most visible benefits arising out of the application of VM is decisions which can be supported by the stakeholders.
- Following a clear job plan, Value Methodology stimulates team efforts and brainstorming during workshop sessions, with the same objectives in every participant's mind. The structured team approach thus builds up a common value culture and enhances every member's understanding of the organization's goals. This might narrow the gap between technical people's daily work and the strategy of Rijkswaterstaat.

Value Methodology stands on a high abstract of problems to understand what we are doing with our assets and what necessary functions we are performing. Besides, value engineering can also provide a detailed analysis of a subsystem and stimulate innovation on improvements. Most importantly, VM enables a link between daily activities to overall objectives. These objectives describe what clients need and will guide a process of decision-making.

Value Methodology exists under several different names. The term Value Engineering has been traditionally used whenever the VM is applied to the construction industry or industrial design; the term Value Analysis for concept planning or process applications; and Value Management, a more comprehensive understanding, applied by organizations to achieve strategic value improvement. There is no essential difference between these terms and they are interchangeable with the name of Value Methodology. VM in this research aims at improving the way of maintaining infrastructure assets based on the concept of value.

In the next two sub-sections, more evidence of the proposed method is given. 1.3.1 introduces briefly how widely Value Methodology had being used in construction projects and what are the benefits; while 1.3.2 discusses some relative methods and tools and gives comparisons. Finally 1.3.3 draws conclusions.

### 1.3.1 Value Methodology in Construction and Transportation Industry

Construction projects face many challenges in the last few decades: budget constraints, safety issues, environmental impact. To solve the problems, pre-planning should be highlighted. Long-term sustainable value for money should be concentrated instead of just low price. Similarly, transportation providers, who face finite budgets and increasing demands for service quality, must find innovative and cost-effective solutions for the construction, operation and maintenance of improved transportation systems. To make full use of our limited resources, we must have the ability to think creatively. Value Methodology, as a helpful management technique, has been developed and practiced in order to improve the performance.

[5] The understanding of Value Methodology is based on a literature study of these books:
Robert B. Stewart, *Fundamentals of Value Methodology*, Xlibis Corporation, 2005
John Kelly, Steven Male, Drummond Graham. *Value Management of Construction Projects*. Blackwell Publishing, 2004
*Value Standard and Body of Knowledge*, SAVE International, June 2007

Value Methodology has expanded to construction and transportation industry since 1960s firstly in the United States. From the mid-1980s value management has been adopted as a value-for-money measure within construction industries of a number of countries. In the UK, the past two decades have seen growth in its development and practice at differing intervention points across a wide range construction project types.[6]

*The United States*

*"Value engineering demonstrates President Clinton's commitment to common sense government. Federal programs like this allow [the U.S. Department of Transportation] to work with state and local governments to build roads that are safe, to stretch the buying power of federal dollars and, in some cases, to complete roadway projects ahead of schedule. ... Value engineering is beginning to pay off literally, and states that have developed active programs are finding the results well worth the investment."*

*— Rodney E. Slater*
*U.S. Secretary of Transportation*

In the United States, Value Engineering is specifically spelled out in Public Law 104-106, which states "Each executive agency shall establish and maintain cost-effective value engineering procedures and processes." [7] In addition, on Page 110, STAT. 186, SEC. 36., the law defined Value Engineering as follows:

*As used in this section, the term 'value engineering' means an analysis of the functions of a program, project, system, product, item of equipment, building, facility, service, or supply of an executive agency, performed by qualified agency or contractor personnel, directed at improving performance, reliability, quality, safety, and life cycle costs.*

State and federal transportation agencies completed 421 Value Engineering studies in 1998. The studies produced more than $750 million in cost savings — the largest in the program's history and a 47 percent increase over the savings in 1997. By applying the value methodology to construction projects, highway and transportation departments saved U.S. taxpayers $1 billion in 2000.[8]

The VM Process can be successfully used at almost any point in the life-cycle of a construction project. The relationship between the potential cost savings/avoidance and the point in the project life cycle where the VM Study takes place is presented in Figure 1 on the following page. The combined experience from both private companies and government has shown that conducting VM studies in the feasibility/planning stage of a project can produce cost avoidance estimates ranging from 20% to 50% of the original estimate for the scope being studied; VM studies conducted later during the final design / construction or during startup/operations can expect to produce cost savings ranging from 3% to 10% of the baseline for the scope being studied.[9]

Generally, three types of value studies are conducted in US:

- Construction Projects. To achieve the optimum design in capital projects are the primary focus of value studies. Subjects have included highways, schools, hospitals, jails, water pollution control plants, bridges, parks, museums, zoos, vehicle maintenance facilities, water treatment plants, lab buildings, environmental projects, etc.
- Product Studies. Many existing products were previously designed and built without being value managed. These items often benefit to the same extent as items previously subjected to a VM Study, and the potential for savings is great. Advances in technology or changes in user requirements provide another basis for potential savings which are greater than the cost of the study and subsequent implementation. In California Department of Transportation, one of the prolific users of value methodology as public sectors at state level in US, VM process is used to

[6] Literature: John Kelly, Steven Male, Drummond Graham. *Value Management of Construction Projects*, Blackwell Publishing, 2004.

[7] Source: *NATIONAL DEFENSE AUTHORIZATION ACT FOR FISCAL YEAR 1996*, [[Page 110 STAT. 186]] Public Law 104-106, 104th Congress

[8] Source: *http://www.value-eng.org/benefits_construction.php*, website of SAVE International

[9] Reference: *http://management.energy.gov/documents/VM20GUIDANCE12-16-04.pdf.* *Value Management, Project Management Practice*, U.S. Department of Energy, Dec 2004

improve the quality of highway products. Value Analysis is applied to identify products that need to be updated due to changing technology, outdated application, or any other changes that affect the standard engineering products. For instance, value studies of headlight glare screens, concrete barriers, and overhead signs have led to statewide modifications.[10]

- Process studies. The Value Analysis process can also be used to improve the quality of organization processes, such as policy and procedures and business practices.

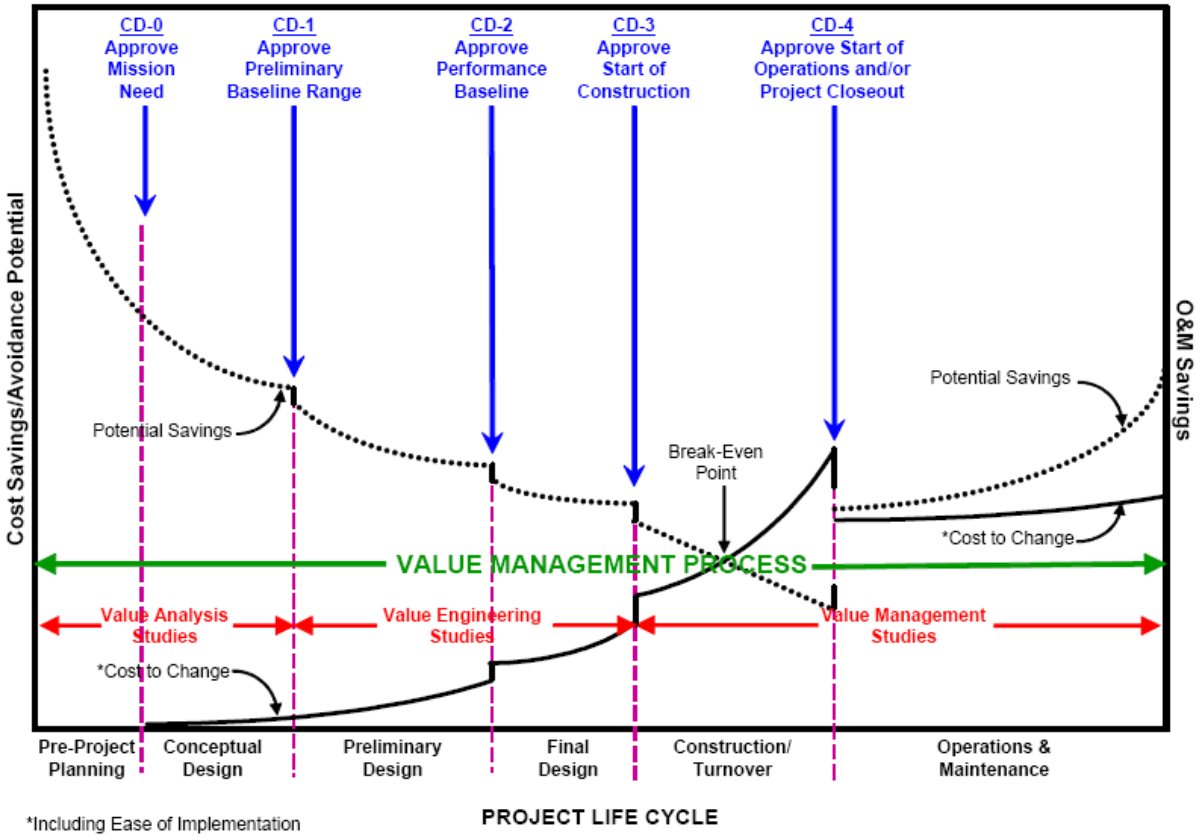



Figure 1. VM and the Project Life Cycle [9]

*The United Kingdom*

In the UK, the significant growth in the development of value methodology in the last two decades leaded to the establishment of a national body to be responsible for its development, namely the UK's Institute of Value Management (IVM).[11]

London Underground embraced Value and Risk Management in the early nineties and started to use it in earnest in the mid nineties. Value Management was applied to the capital investment programme in the form of Value Engineering during the Outline and Detailed Design phases of projects.

Similar approach is being taken in Highways Agency in their maintenance projects.[12] A list of attributes, which includes safety, value for money, reduction of disruption and environment, and clearly stated weights comprise a scoring matrix used by managing agents and Highways Agency personnel to assign priorities to road maintenance projects. Then Value Engineering is used for detailed design to ensure the optimum of value. It is called route map for the application of VM in maintenance projects. This will be introduced in Chapter 2 in this thesis report.

Furthermore, VM programmes have assisted in achieving value improvement for major

[10] Reference: *http://www.dot.ca.gov/hq/oppd/pdpm/chap_pdf/chapt19.pdf*.
*Value Analysis, Project Development Procedures Manual 2007*, California Department of Transportation.
[11] Information below mainly comes from IVM website: *www.ivm.org.uk*. (Accessed July 15th, 2008)
[12] Source: Value Management of the Regional Roads Programme, Highways Agency, January 2006.

organizations such as BP, Retail, British Airways, BAA, Pfizer, Stanhope, and water and rail companies. Substantial improvements have been achieved in the return on investment of capital projects, up to 50% improvement in capital productivity.

Besides the capital cost reduction, benefits of VM also include shared understanding, ownership and commitment within project team, and in such areas as reorganizations, business and production processes, in decision support and the development of risk mitigation.

*The Netherlands*

The practice of Value Engineering in the Netherlands started in recent years. ProRail is striving with its practice on its projects by trying to demonstrate the benefits for the project out of practicing Value Engineering on it. Value Engineering is commonly implemented in design and redesign phase of a project. One case study of ProRail will be given in Chapter 2. Besides, consultant and engineering companies like Grontmij, Movares and Witteveen & Bos also own their knowledge of Value Engineering, to achieve best value for money solutions for clients.[13]

*Conclusions*

From the development and application of Value Methodology, we can see that VM is commonly involved in the early development and design phase of a construction project to save life cycle cost. There is much evidence of the benefits, especially in infrastructural projects which require large amount of money. A lot of success in the use of value methodology was gained in many public sectors all over the world, which brings confidence for its application in Rijkswaterstaat.

Although Value Methodology has not been applied on a large scale to develop optimal maintenance strategies, there are still some successful applications of VM on existing objects or maintenance projects such as in U.S. Department of Energy, California Department of Transportation and British Highways Agency. Manufacturing industry sees more benefits from applying VM on existing products, to improve the process, methods and materials. The key of VM is to understand a system and its functions, find critical functions based on the value system of customers or stakeholders and create innovations by asking question “what else can perform the same function”. It could also help with an existing infrastructure asset or maintenance process in the same way.

### 1.3.2 Relative Methods and Tools

Regarding preservation of existing systems, one might quickly comes out with some methods or tools such as Life Cycle Cost Analysis (LCC), Reliability Centered Maintenance (RCM) based on Failure Mode Effects and Criticality Analysis (FMECA) and Reverse Engineering (RE). Value Methodology (VM) differs from these tools either in the view of looking into problems, the objectives or the approach. Besides, Systems Engineering (SE) is another management technique which is comparable to VM. Thus, paragraphs below analyze the relations and difference between VM and these methods or tools.

*SE*

Systems Engineering, the art and science of creating successful systems, is becoming increasingly important in civil engineering industry because systems for use as public services become increasingly complex and interconnected. It is a rapidly developing field, and consequently there is no universally accepted definition. Here is the definition from International Council on Systems Engineering (INCOSE): [14]

*Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering considers both the*

[13] Information is from Timme Hendriksen, the Value Manager of ProRail.
[14] Reference: *INCOSE Systems Engineering Handbook*, Version 3, June 2006

*business and technical needs of all customers with the goal of providing quality products that meet the user needs.*

SE was first used in the telephony sector as a method for implementing operability between different components of the telephone system in US. As systems were becoming increasingly more complex since World War II, more applications of SE began to accelerate in space and weapons industry. In the Netherlands, SE was introduced to ProRail from 1998. Rijkswaterstaat applied the discipline as part of its A4 Burgerveen-Leiden trunk road construction project. In the meantime, SE has become the standard methodology for integrated contracts, especially from design phase, at ProRail as well as for Rijkswaterstaat.[15]

The objective of SE is to provide structure and insight to the complexity of the object to be produced, from system, subsystem, component to element level. It provides an integrated and structured set of methodologies for successfully managing the whole life cycle of projects while Value Methodology can be embedded in any moment when decisions need to be made.

The Value Engineering Handbook from IDA (Institute for Defense Analysis) [16] analyzes all VM opportunities during each phase of a system's life cycle in a Systems Engineering context. Figure 1 in the last section also shows the possibilities and potential savings. During maintenance and operation phase (called preservation), opportunities for VM may exist for a long time. Product life cycles are being extended; advances in technology or changes in user requirements provide a basis for potential savings on those existing items which were never subjected to a VM analysis.

In a word, SE is a systematic approach to build up an object of complexity while VM is useful at some moments to ensure best value for money. To improve the preservation of infrastructure assets and make decisions on improvement proposals, VM is more suitable.

*LCC*[17]

Life cycle cost, as implied in its name, refers to the total cost of ownership over the life of an object. When a renewal or replacement maintenance project takes place, the life cycle cost covers expenditure in areas including planning, engineering work, procurement, installation and maintenance in its life span. LCC principles tell us, while the initial investment is a factor in decisions, it is not the only factor.

Life cycle cost analysis is an economic technique for predicting present and future costs for the purposes of comparing options and/or determining the most probable future facilities management cost of a facility. Cost plays a major role in decisions of maintenance strategies, because maintenance is a matter of trying to find the point at which, at the lowest possible annual cost, calculated over the longer term, functionality can be guaranteed. (Defined in Basic level of maintenance of the network of main roads in the Netherlands, Rijkswaterstaat, 2002)

However, cost is not the only criteria. A fundamental principle of Value Methodology is that options generated through innovation are evaluated using life cycle cost criteria. However, it is also a principle of VM that the cost effectiveness equation takes account of the whole value of the project to the client, not only cost. For example, the effectiveness of an Ikea supermarket may be judged in terms of the number of customers who can park their cars, move effectively all through the market space, find whatever they need, pass through the checkout point without too much waiting, return to their car, leave and allow space for the next customer. The value of the market is more complex than just providing the lowest cost building and parking space.

[15] Reference: *Guideline Systems Engineering for Public Works and Water Management*, English version, May 2008.

[16] Reference: Jay Mandelbaum，Danny L. Reed，*Value Engineering Handbook*，IDA Paper P-4114，September 2006.

[17] Understanding of LCC comes from Life Cycle Cost Handbook from Alaska Department of Education & Early Development. (See *http://www.eed.state.ak.us/facilities/publications/LCCAHandbook1999.pdf* ) and literature: John Kelly, Steven Male, Drummond Graham. *Value Management of Construction Projects*, Blackwell Publishing, 2004.

*RCM based on FMECA*[18]

Reliability Centered Maintenance is an industrial improvement approach focused on identifying and establishing the operational, maintenance, and capital improvement policies that will manage the risks of equipment failure most effectively based on the reliability of the various components of the system or product in question. The first and most important part is to analyze the system or product using a Failure Mode Effects and Criticality Analysis, which determines the different ways a system can fail. The second part of the analysis is to apply the "RCM logic", which helps to determine the appropriate maintenance tasks for the identified failure modes.

In a word, RCM is an engineering framework which can generate a complete maintenance regime with detailed maintenance tasks based on failure and risk analysis. The key approach is to identify critical failure modes and define maintenance tasks for these modes. By contrast, the function analysis in Value Methodology focuses on identification of critical functions which is guided by what the clients need. Furthermore, a technical function analysis in VM also helps to understand functions of subsystems and find a solution for failures.

Application of RCM on complicated systems tells that, developing an effective RCM program will optimize the maintainability of the system. That is why in NHK project Rijkswaterstaat is expecting contractors to follow a RCM approach and also trying on RCM as a knowledge base. An investigation among technical people involved in NHK project shows that, RCM is a useful approach of knowing the installations and the way to maintain them. But it requires much time and money. Furthermore, as it goes too much into detail, a method on strategic level which relates to financial planning should be developed. Value Methodology may fill this gap.

*RE*[19]

The process of duplicating an existing part, subassembly, or product, without drawings, documentation and specifications, or a computer model is known as reverse engineering. RE is often done when the documentation of a particular product has been lost or is irretrievable. The purpose is mostly to make a new product that does the same thing without copying the original one.

In the reverse engineering and redesign methodology of Otto and Wood, RE initiates the redesign process, wherein a device is predicted, observed, disassembled, analyzed, tested, 'experienced,' and documented in terms of its functionality, form, physical principles, manufacturability and assemblability. By experiment with product components and creating refined function structure of actual product, RE provides concrete experience of existing objects from function point of view. In this broader understanding of RE, the function analysis phase of Value Methodology when applying on existing objects is a process of reverse engineering.

RE is commonly applied in software and hardware product but not a whole infrastructure asset since usually these assets are too large and have little possibility to be reproduced. However, it can still be used on a small part such as an engine system, and RE in this way can stimulate innovations on improvements. By contrast, VM is a management technique which has a broader meaning. The first task, guided by a list of value attributes, is to identify which function or subsystem is critical and is worth being given more studies. Here these studies can be detailed function analysis or even a whole reverse engineering process. So RE might be a supporting tool of VM in "generating alternatives" phase.

[18] Understanding of RCM is based on technical standard SAE JA1011： *Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes*. Society of Automotive Engineers. Pittsburgh, PA. 1999; RCM website created by Relex Software Corporation: *http://www.reliability-centered-maintenance.com/*; and opinions from technical people in Rijkswaterstaat who are trying on RCM in NHK project.

[19] The introduction of RE is concluded from literature study of : Vinesh Raja and Kiran J. Fernandes (Eds.), *Reverse Engineering-An Industrial Perspective*, Springer series in advanced manufacturing, 2007; and paper: Otto, K and Wood, K '*A Reverse Engineering and Redesign Methodology for Product Evolution*' Proceedings of the 1996 ASME Design Theory and Methodology Conference 96-DETC/DTM-1523 Irvine, CA (1996).

*Conclusions*

The above comparisons show that, there are similarity and overlapping between Value Methodology and these methods or tools. But they have different contributions on the preservation of an infrastructure asset. LCC helps with the financial evaluation when making decisions during life cycle of the system including preservation period; RCM aims at developing a cost-effective and detailed maintenance programme; RE might contribute in stimulating innovations in improvements of components but not the whole system; SE is a broader management technique than VM with the objective to build up a system of a whole life-cycle; VM may contribute on improvement proposals and make decisions on them during preservation phase.

### 1.3.3 Conclusions

It is the problems in the evolution of Rijkswaterstaat that start this research. Value Methodology is proposed based on its significant advantages which match the problems well. Besides, more evidence of VM can be seen from its applications and comparisons with other methods and tools.

- A lot of success in the application of Value Methodology was obtained in many public sectors all over the world. It implies a possibility of using VM in Rijkswaterstaat.
- Application of VM on existing objects and maintenance projects is not new; there have been some successful cases in public sectors in construction industry. Moreover, benefits from applying VM on existing products in manufacturing industry sees opportunities with existing infrastructure assets.
- Among possible methods and tools, VM stands out because it is able to focus on a high abstract of the complete picture and contribute on improvement proposals which match the problems well.

In a word, **it is worthwhile to research and try on Value Methodology in Rijkswaterstaat, and see how it can be used to solve problems brought by the significant evolution in Rijkswaterstaat. VM is the starting point and concentration of this thesis research.**

## 1.4 Research Objectives & Questions

### 1.4.1 Objectives

The objective of this master thesis project is to:

*Develop a Value Methodology approach to:*

- *Identify and specify maintenance improvements on infrastructural assets based on function analysis;*
- *Develop attributes and a scoring framework to guide decision-making on renewal and modification projects;*

### 1.4.2 Questions

As this research would be the first attempt of Value Methodology in Rijkswaterstaat and there was not much practice of VM in maintenance domain, the picture of the project was not clear at the beginning. Efforts are contributed to seek for answers to these explorative research questions:

- How can VM be used on existing objects in identifying maintenance improvements?
- What does an adequate decision-making picture on renewal and modification projects look like based on the value concept in VM?
- Can VM be well implemented in Rijkswaterstaat? (Does it fit in the culture? Does the decision made by VM fit in the budget?)

## 1.5 Research Approach & Layout of the Report

This research follows the approach shown in Figure 2.

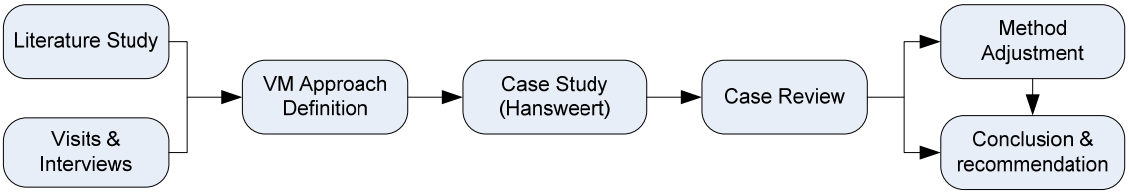



Figure 2. Research Approach

The research is done based on a case study. First a rough theoretical approach was derived according to a literature study and more insight of the project. Afterwards, an infrastructure asset was chosen as the case study to test the theoretical approach. The author worked as the value engineer. The proposed approach was adjusted owing to further discovery and experience. After reviewing the case study, an improved method is resulted.

This final report is divided into two main parts. Chapter 2 represents the theoretical part which includes basic knowledge of Value Methodology, and the theoretical VM approach that the case study follows. Chapter 3 concentrates on the case study and how the improved approach is developed. Chapter 4 discusses all the research questions and problems based on all the work had been done. Conclusions and recommendations are given in the final chapter.

It is also worth noting that during this research, an investigation of the application of VM in Dutch ProRail and British Highways Agency was carried out by meetings with value managers in both organizations. A brief introduction is provided in Chapter 2 which helps to explore a good VM approach.

# 2 Value Methodology

This chapter consists of three sections. The first section briefly introduces Value Methodology and its detailed job plan. A typical function analysis technique which lies in the heart of VM is particularly introduced in the first part. Then the VM practice in ProRail and British Highways Agency is briefly described in the second section. Based on the first two parts, together with the situation of Rijkswaterstaat, a general VM approach which the case study follows is given in the last section.

## 2.1 Introduction of Value Methodology & Function Analysis

According to SAVE International Value Standard[20], the value methodology is defined as a systematic process used by a multidisciplinary team to improve the value of a project through the analysis of its functions. Although there are numerous views to describe the notion of "value", it is defined in SAVE International as a fair return or equivalent in goods, services, or money for something exchanged. In the Value Engineering world: value is commonly represented by the relationship:

$$\text{Value} \approx \text{Function/Resources}$$

where function is measured by the performance requirements of the customer and resources are measured in materials, labor, price, time, etc. required to accomplish that function. Maximum value as defined by Burt[21] is obtained from a required level of quality at least cost, the highest level of quality for a given cost or from an optimum compromise between the two. Based on this understanding, this research considers Value Methodology as a systematic method to make a trade-off between functionality and cost. The best way to achieve more value of the existing assets for Rijkswaterstaat is to improve their functionality while remaining or reducing the sum of the investments and annual maintenance cost. So functionality and cost sorts should be well defined in their value system, in order to guide the whole VM process.

### 2.1.1 The Value Methodology Job Plan

Within the Value Methodology, there is an organized approach which is called VM Job Plan and must be followed in order to obtain significant value improvements. Following these steps in sequence, trying to solve a problem before it has been thoroughly understood and analyzed, is the key to the success of VM.

The following paragraphs describe the job plan of value study as used in SAVE International Value Standard. This job plan includes six phases, as analyzed in Figure 3 (stage 2):

[20] SAVE International, originally founded in 1959 as the Society of American Value Engineers, is the premier international society devoted to the advancement and promotion of the VM. Value Standard 2007 can be found on the website: *http://www.value-eng.org/pdf_docs/monographs/vmstd.pdf*.

[21] Reference: Burt, M.E (1975) *A Survey of Quality and Value in Building.* Building Research Establishment, Garton, Watford. Herts

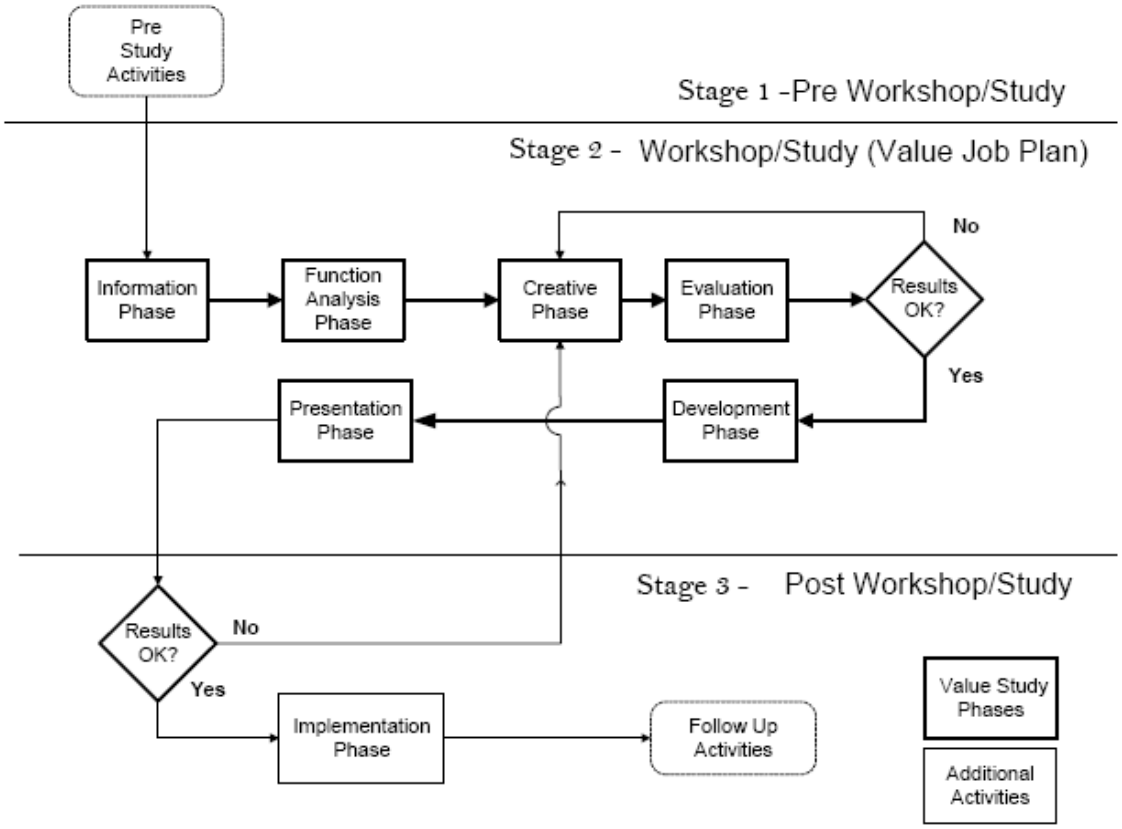



Figure 3. Value Study Process Flow Diagram [SAVE International Standard 2007]

**a) Information Phase**

**Purpose:**

Understand the current state of the project and constraints that influenced project decisions.

**Common Activities:**

- Obtain project data and information and key documents such as scope of work definition, drawings, specifications, reports, detailed project cost information, quality data, marketing information, process flow charts, etc.
- Identify and prioritize strategic issues of concern. Further define the scope and objectives (management expectations) of the study
- Project Team presents the original and/or present design/product/process concepts
- Perform competitive benchmarking analysis
- Determine the study schedule; dates, times, location and other logistical needs
- Distribute information about the project for team member review
- Understand project scope, schedule, budget, costs, risk, issues, non-monetary performance.
- Confirm the most current project concept
- Identify high-level project functions
- Visit site or facility
- Confirm success parameters

**Typical Outcome:**

This phase brings all team members to a common, basic level of understanding of the project, including tactics, operations, and specifics of the subject. The functional understanding establishes the base case to identify and benchmark alternatives and mismatches and set the agenda for innovation.

**b) Function Analysis Phase**

**Purpose:**

Understand the project from a functional perspective; what must the project do, rather than how

the project is currently conceived.

**Common Activities:**

- Identify the project functions (team format strongly encouraged)
- Classify project functions
- Develop function models (Function Analysis System Technique, Function Tree)
- Dimension the model with cost drivers, performance attributes and user attitudes to select value mismatched functions to focus the creativity phase
- Estimate worth of functions to select value-mismatched functions on which to focus the creativity phase

**Typical Outcome:**

This phase focuses the team on validating that the project satisfies the need and objectives of the customer. It provides a more comprehensive understanding of the project by focusing on what the project does or must do rather than what it is. The team identifies value-mismatched function(s) on which to focus in order to improve the project.

### c) Creative Phase

**Purpose:**

Generate a quantity of ideas related to other ways to perform functions

**Common Activities:**

- Identify the project functions (team format strongly encouraged)
- Conduct creative warm-up exercises
- Establish rules that protect the creative environment being developed
- Employ group idea stimulation techniques
- Generate alternate ideas that may improve value. (Brainstorming, Gordon Technique, Nominal Group Technique, TRIZ, Synetics)

**Typical Outcome:**

The team develops a broad array of ideas that provide a wide variety of possible alternative ways to perform the function(s) to improve the value of the project.

### d) Evaluation Phase

**Purpose:**

Reduce the quantity of ideas that have been identified to a short list of ideas with the greatest potential to improve the project

**Common Activities:**

- Clarify and categorize each idea to develop a shared understanding
- Discuss how ideas affect project cost, and performance parameters
- Select and prioritize ideas for further development (Pugh Analysis, Kepner-Tregoe, Life Cycle Costing, Choosing by Advantages, Value Metrics)
- Explain how ideas are to be written as stand-alone risk-reward investment proposals

**Typical Outcome:**

The team produces a focused list of concepts that warrant quality time to develop into value-based solutions that can be implemented into a project or a project feature.

### e) Development Phase

**Purpose:**

Further analyze and develop the short list of ideas and develop those with merit into value alternatives.

**Common Activities:**

- Compare the study conclusions to the success requirements established during the Information and Function Analysis Phases
- Prepare a written value alternative for each idea selected for further development
- Assess and allocate risk judgments and costs, where appropriate

- Conduct cost-benefit analysis
- Generate sketches and information needed to convey the concept
- Confirm that an alternative should be further developed
- Finish initial alternative development
- Develop an action plan to define implementation steps, dates, and responsibilities for each value alternative

**Typical Outcome:**

The Value Study team creates alternatives and low-, medium-, and high-risk scenarios and offers these alternatives to senior management as options that address the Pre-Workshop strategic objectives.

**f) Presentation Phase**

**Purpose:**

Present value alternatives to management team and other project stakeholders or decision makers.

**Common Activities:**

- Prepare presentation and supporting documentation
- Compare the study conclusions to the success requirements established during the Information and Function Analysis Phases
- Offer to management "risk-reward" innovation scenarios to select value alternatives for implementation
- Exchange information with the project team
- Ensure management has full and objective information upon which they can make decisions
- Outline an anticipated implementation plan
- Prepare formal report

Common Value Study products include a briefing document, risk analysis; cost vs. worth comparisons; Present worth analysis; advantages vs. disadvantages

**Typical Outcome:**

Ensure management and other key stakeholders understand the rationale of the value alternatives. Also generate interest to sanction implementation.

### 2.1.2 Function Analysis

Function Analysis lies in the heart of Value Methodology, with the purpose of identifying unnecessary functions or those represent poor value. This phase of VM is the main point of departure between VM and other problem solving approaches. Take a pen as an example. If a pen does not work well and the user find it difficult to make marks on paper, he or she simply throws it away and uses another pen instead, it is a way to solve problems but it is not a VM approach. If VM is followed, the first step is to understand how the pen works by function analysis, and identify which function does not perform well. By asking question "how to improve this function" or "what else can perform the same function", we can search for solutions for the problems. Function Analysis initiates the problem solving process.

The pen is a very simple example. However, when we look into a complicated system with a lot of subsystems, or a complicated process of manufacturing or service, we need to make clear how the functions relate to each other and provide the project team with a vision of these function relationships. The Function Analysis System Technique (FAST), a powerful diagramming technique for analyzing the relationship of functions, was developed by Charles W. Bytheway of the Sperry Rand Corporation and has been widely used by government agencies, private firms and value consultants. Besides relations between functions, FAST gives insight in missing functions and levels of abstraction, which will be demonstrated in case study phase of this research.

In this section, function definition, classification and FAST technique is briefly introduced[22].

[22] Reference: J.Jerry Kaufman and Roy Woodhead, *Stimulating Innovation in Products and Services*, John Wiley & Sons, 2006

*Function Definition*

Function, the specific purpose or intended use for any product, process or facility, is the characteristic which makes it work or sell. In short, it is the reason why the owner, customer, or user needs a product.[23]

Instead of several concepts described in many sentences, the first principle in defining a function in Value Engineering is using only two words ----a verb and a noun. The verb answers the question, "What does it do?" (It may generate, control, pump, emit, protect, transmit...). And the noun answers the second question "What does it do this to?" (electricity, temperature, liquids, light, surfaces, sound...).This noun must be measurable or at least understood in measurable terms, since a specific measurement must be assigned to it during the later value process which relates cost and performance to function.

These are some examples in construction studies listed in Table 1:

| Objects | Functions |
|---|---|
| Structural Columns | Transfer Load |
| Interior Walls | Separate Space |
| Doors | Control Access |
| Clerestory Windows | Admit Light |
| Ceiling Tile | Attenuates Sound |

Table1. Examples Function Definition

Introduction and practice on function definition should be prepared before workshops.

*Function Classification*

There are several classifications of functions which include: basic functions, secondary functions, higher order functions and assumed functions.

**a) Basic Functions**

A basic function is defined as the principal reasons for the needed existence of a product or service operating in its normally prescribed manner. The basic function answers the question, "What must it do?" An item may possess more than one basic function.

There are four rules that govern the selection of basic functions. These include:

- Once defined, a basic function cannot change, as it becomes the principal work that the system of intrinsic functions is expected to do.
- The cost contribution of a basic function is usually a minimal percentage of the total product cost.
- You cannot sell supporting (secondary) functions without performing the basic function satisfactorily.
- Loss of the basic function causes loss of the market value and worth of a product or service.

**b) Secondary Functions**

The secondary functions answer the question, "What else does it do?" Secondary functions are support functions and usually result from a particular design configuration. Generally, secondary functions contribute greatly to cost and may or may not be essential to the performance of the basic function.

**c) Higher-Order Functions**

Higher-order functions represent the specific needs that the basic functions exist to satisfy. These functions identify the overall need of the customer and generally relates to the "need" statement of a project's need and purpose. For example, the basic function of a classic mousetrap is to *KILL MICE*. The higher-order function would be to *ELIMINATE MICE*.

[23] Reference: Robert B. Stewart, *Fundamentals of Value Methodology,* Xlibis Corporation, 2005

**d) Assumed Functions**

Assumed functions describe functions that lie beyond the scope of the study. They are generally not part of the function analysis process unless the level of abstraction changes the scope of the problem.

Here is an example of basic and secondary functions:

HVAC system----The basic function of the HVAC System is to *CONDITION AIR*. The other functions such as *HEAT AIR, COOL AIR, MOVE AIR, CONTROL HUMIDITY, DISTRIBUTE AIR,* etc., are secondary functions. Unwanted functions such as *GENERATE NOISE* and the aesthetic function of *ENHANCE DECOR* also exist.

*Building a FAST diagram*

The Function Analysis System Technique analyzes the relationship of functions and builds up a function diagram, by asking questions of HOW and WHY.

HOW is read from left to right and WHY is read from right to left. Using the examples below, if we were addressing the function *MAKE MARKS* and asked the question, "How do we make marks?" the answer, in the form of a function could be *CONTRAST COLOR*.

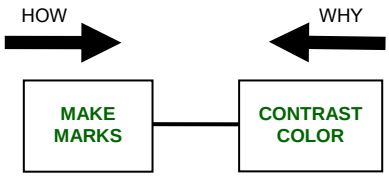



Figure 4. Build a Pencil FAST Model

If we continued in the HOW direction and asked, "How do we contrast color?" the answer could be *DEPOSIT MEDIUM*, as shown in the figure below.

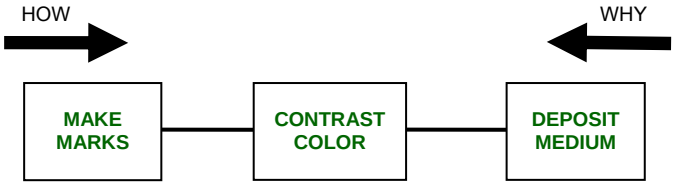



Figure 5 Deposit Medium

To test the logic of the example above the functions can read in the reverse WHY direction. "Why do we want to deposit medium?" "To contrast color." "Why do we want to contrast color?" "To make marks." If the team agrees with the answers, we can continue to expand the FAST model, either in the WHY or HOW direction.

There is also vertical direction called WHEN direction, which is not part of the intuitive logic process but it supplements intuitive thinking. WHEN is not a time orientation, but indicates cause and effect. Referring to Figure 6, a FAST diagram for pencil, "When you *ABSORB MEDIUM*, you should *RUB ERASER.*" Since the independent function is not on the major logic path, changing the function would not significantly affect the basic function.

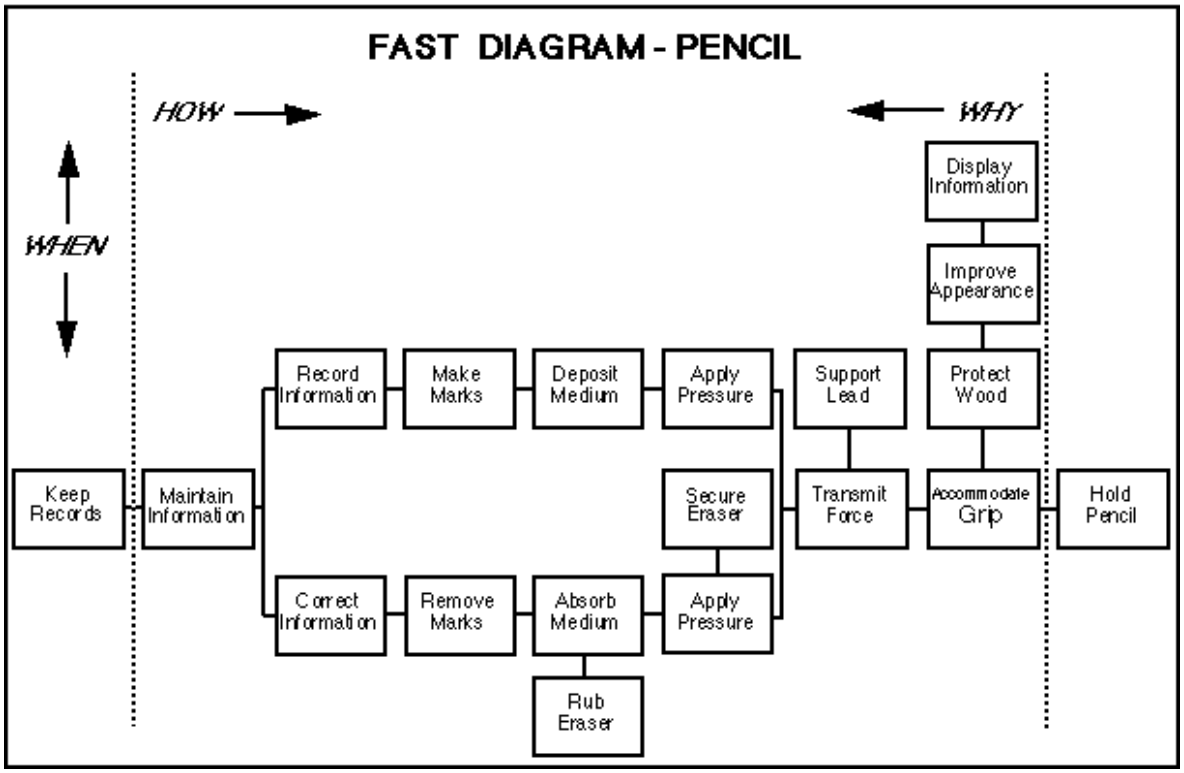



Figure 6. FAST Diagram of pencils [24]

From the example FAST diagram of pencils above, we can see the structure of a FAST diagram. The basic FAST model is shown below:

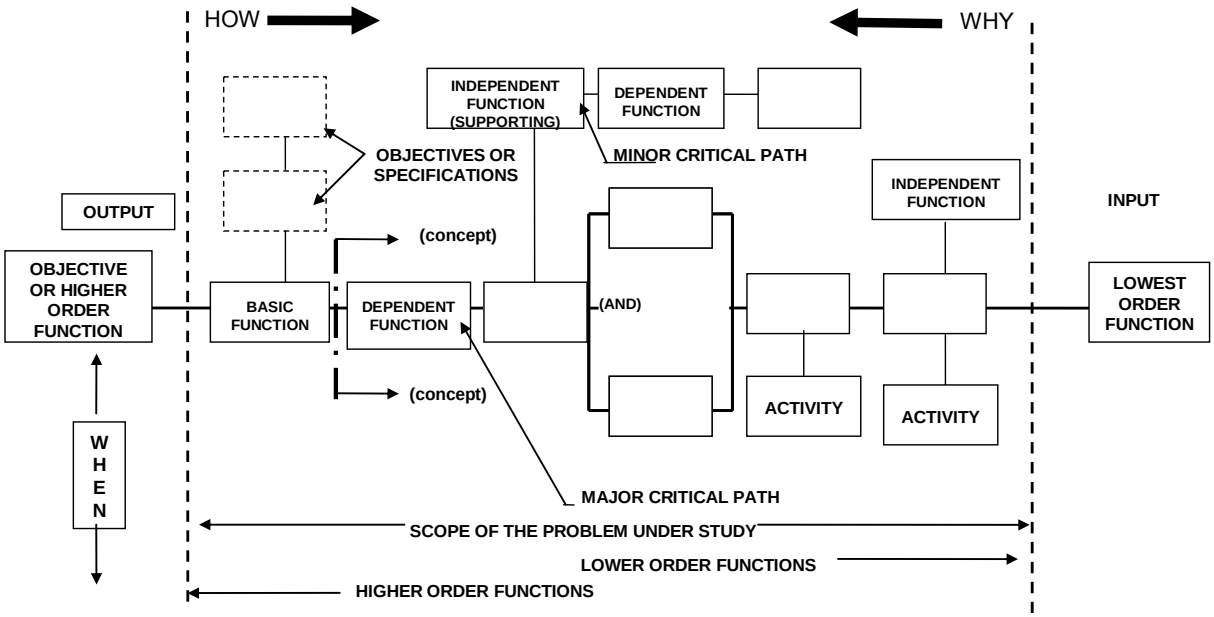



Figure 7. Basic FAST model [25]

[24] Adapted from an example developed by J. Jerry Kaufman. Source: *http://www.npd-solutions.com/va.html*

[25] Source: Jim Wixson, Presentation of Function Analysis and Decomposistion using, Lockheed-Martin Idaho Technologies Co., Inc.

The FAST Diagram is built upon the left-right logic of HOW and WHY and the up-down logic of WHEN. There are several additional elements that are necessary to further communicate the functional relationships.

**Scope lines:** represent the limits of the value study and are shown as two dashed vertical lines on the FAST diagram. The basic function will always be the first function to the immediate right of the left scope line. The function to the immediate left of the left scope line is the higher order function, or output. The right scope line identifies the beginning of the value study and separates the assumed function, or input, from the scope of the study.

**Highest Order Function:** it is the objective of the value study and located to the left of the basic function and outside of the left scope line. Any function to the left of another function is a "higher order function" because reading the FAST model in the WHY direction will lead you to the basic function and the highest order function of the subject under study.

**Basic Function:** those functions to the immediate right of the leftmost scope line represent the purpose or mission of the product or process under study. Once determined, the basic function will not change.

**Secondary Functions:** all functions to the right of the basic function selected to satisfy the basic function, which are subject to change.

**Lowest Order Function:** function to the right and outside the right-hand scope line, which represents the input side and turn on or initiate the functions within the focus of study.

**Logic Path Functions:** any function on the how or why logic path. Changing a function on the major logic path will alter or destroy the way the basic function was performed previously. If we want breakthrough innovation, this is where we aim.

Before starting the FAST process, three questions should be asked, in order to identify the scope lines.
- What problem or opportunity are we about to resolve?
- Why do you consider this problem or opportunity?
- Why is a solution necessary?

Besides, performance attributes are also important issues to be discussed before making FAST diagram. After FAST diagram is determined, functions are analyzed by relating them with cost and performance attributes.

*Dimensioning the FAST diagram*

The next step in the process is to dimension the FAST model or to associate information to its functions. FAST dimensions include, but are not limited to: responsibility, budgets, allocated target costs, estimated costs, actual costs, subsystem groupings, placing inspection and test points, manufacturing processes, positioning design reviews, etc. Important aspects to dimension a FAST model are clear performance measurements and costs.

A Cost Function Matrix is prepared to identify the cost of providing each function or function group by associating the function with a mechanism or component part of a product. Product functions with a high cost-function ratio are identified as opportunities for further investigation and improvement.

Performance attributes and their relative relations should also be prepared before building FAST diagram. And the relative influence that the functions have on performance should also be considered. Then a performance sensitivity matrix can be created below the FAST diagram to show which functions have major contribution or minor contribution to the performance.

Those functions indicating a potential poor value, which have relatively high cost with low contribution to total performance, should be considered as critical functions. Efforts should be emphasized on these functions to improve the total value.

## 2.2 VM Practice in ProRail & Highways Agency

In order to get more insight of Value Methodology in practice, visits were paid to value engineers working for value studies in Dutch ProRail and the British Highways Agency which are pioneer organizations in the application of VM in both countries. This section introduces briefly how these organizations apply VM in their design or maintenance projects. Some of their experience is very useful for developing a VM approach for Rijkswaterstaat.

### 2.2.1 Tailored Value Engineering in ProRail [26]

*With VE the organization has a decision making tool to decide whether a design delivers value and if not what could be done to improve value.*

*— Timme Hendriksen*
*VE Program Manager of ProRail*

Value Engineering was introduced within ProRail, manager of Dutch railways, as a part of the Timme Hendriksen's thesis (2002) on how VE could be implemented within the organization. In 2004 Value Engineering became a part of corporate policy and started to grow into a Program. Now 80% of capital projects within ProRail, which cost more than €10 million, apply Value Engineering in concept or preliminary design phase of the projects. Their application of VM is based upon constrained resources, creating value awareness and building trust between stakeholders.

However, a full size of VE Job Plan, which means 5 days' workshop session in SAVE International Standard, is not an option in ProRail mainly because of time and budget limitations. Senior management support, but do not enforce the application of VE. Furthermore, the way of in-house VE workshops can spread out the workloads of VE team members and integrate the critical path activities in a project, thus save time for VE program. These two reasons drive ProRail to tailor a VE program to client's demand.

Based on Timme's experience within ProRail, the most important condition for tailoring a successful VE study is to respect three basic principles of Value Methodology:

- **The systematic approach using the VE Job Plan.** It is very important to follow the steps of VE Job Plan and do not skip any because each phase has its purpose and is the input for the next. When looking into steps and tools separately, one is not performing VE. A successful VE study contains sufficient preparation, deep understanding and analysis of functions, brainstorm within multi-disciplinary team and a good framework for evaluation.
- **Function analysis.** As stated in section 2.1.2, function analysis makes VM special. It enables a common language for every team member to understand the problems. The abstract formulation creates maximum freedom to generate new ways to do the same function by asking HOW.
- **A multi-disciplined team**. Inviting right people to the value team is one of the success factors of VM. Not only a multi-disciplined team with relevant expertise and representation should be set up, but also a multi-skilled facilitator is needed to guide the workshop session.

Following these three principles is a success factor of tailoring a value study and should also be the principle for a tailored VM approach in this thesis research.

Timme introduced a best case practice of ProRail which is included in Appendix A of this report. From the case study, we can find the application of Function Analysis, as one of Value Methodology tools, and the benefits of introduction of Value Engineering as savings of 55 million euros, increase in performance by 18%.

What is worth mentioning here is the performance criteria they derived for the case practice which is listed in Table 2. These criteria are used to assess alternatives.

[26] The information provided below is based on the conversation with the VE Manager of ProRail: Timme Hendriken and his paper: *Tailoring Value Engineering to the Client's Demand*, AVS, ProRail
The case practice is from internal reports on Value Engineering projects of ProRail.

| Criteria | Weight (0-1; sum W=1) |
|---|---|
| **1. Constructability**<br>Way of construction<br>Choice of materials | <br>0.30 |
| **2. Maintainability**<br>**a) rail related**<br>**b) non-rail related**<br>Choice of materials<br>Reaching areas to be maintained<br>Sensitivity to be maintained | <br>0.15<br>0.05 |
| **3. Fitness in future**<br>Flexibility for: expansion possibilities<br>Platform<br>Speed (rail)<br>Weight (rail) | <br>0.13 |
| **4. Availability**<br>a) rail<br>b) road | <br>0.22<br>0.05 |
| **5. Aesthetics** | 0.1 |

Table 2. Performance Attributes (ProRail, 2006)

### 2.2.2 Value Management on Maintenance Projects in Highways Agency [27]

*A list of clear value attributes is the most important success factor when applying Value Management. Although any decision-making process is more or less subjective, we can make it more objective when we define the criteria more clearly.*

*— Emma Langman*
*Project Manager/Value Expert of Atkins*

British Highways Agency is responsible for the operation and stewardship of the strategic road network in England on behalf of the Secretary of State for Transport. Maintenance of almost all of England's 9,500 kilometers of motorways and trunk roads is the responsibility of the Agency. All the maintenance work is contracted out to private parties: managing agents investigate, design, manage and control repair work while maintenance contractors carry out the work.

In late 1990s, a strategy promoted to the Highways Agency in "A New Deal for Transport: Better for Everyone" is developing the Agency to a network operator rather than a road builder. One of the objectives is to carry out the Government's targeted programme of investment in trunk road improvements. By that stage the Agency's priorities had moved away from new road building to focus on maintenance and making better use of the existing infrastructure. (Actually this is similar to the strategy of Rijkswaterstaat, developing itself to a network manager and investing more on maintenance of his assets, as introduced in the first chapter.)

Atkins, the largest engineering consultancy company in UK, is one of the managing agents who take charge of Value Management approach of the regional road programme. A trip to Atkins UK was arranged during this thesis research, with the purpose to learn from the success of the Agency's VM applications. Four VM experts were invited to the meeting, named Emma Langman, Mark Jordan, Steven Finnie and David Wightman. Their VM procedure was introduced, and the success factors were discussed.

[27] General information about the Highways Agency is from its website: *http://www.highways.gov.uk/* and the Department of Transportation website: *http://www.dft.gov.uk/.*
Information about VM application in the topic of maintenance is based on two reports: a) *The Highways Agency: Maintaining England's motorways and trunk roads*, Thirty-second Report of Session 2002–03. b) *Value Management of the Regional Roads Programme,* Highways Agency, January 2006.
Appendix 2 comes from the internal documents from Atkins.

To improve the functionality of main roads, first some capital maintenance schemes (renewal projects) are derived from inspection report, safety report and database. These maintenance proposals are then discussed in a Value Management workshop in order to assess the technical and economic merits. Proposed maintenance projects are scored based on four criteria with relative weights (see Table 3), and are prioritized. Projects with high priorities which fit in the budget are then selected to more detailed design through Value Engineering to ensure that the best value is achieved. In this way, Value Management allows maintenance projects to be assessed systematically and consistently.

The ongoing VM procedure with early contractors involved goes step by step following a strict order. For projects that are fully prepared and submitted with all the required supporting information, the Value Management process is aimed at benefits such as:

- Brief Traffic Operation Directorate (TO) on the more detailed analysis of the projects on the network and allow input to the projects that are put forward.
- Provide TO and managing agents with an early indication of which projects require further Value Engineering.
- Provide scores to help prioritize projects within Areas and Regions.
- Allow the whole programme of works for the Area and Region to be considered.
- Contribute to the achievement of the Highways Agency strategic maintenance objectives.

The application of Value Management and Value Engineering in Highways Agency can be dated from 1996. Value Management seeks to review, confirm and control project objectives at key stages of scheme/project development. Value Engineering considers how best to achieve the objectives at the lowest whole life cost and at appropriate quality. The most significant benefit of using VM is better evidence to support the derived proposals, thereby improving the quality of maintenance proposals and the basis of its decisions between projects. To support this decision-making process, accurate defined criteria are super important success factors.

Table 3 shows an example of the scoring framework being used when assessing pavement small works with guidance on how to assess and score the four criteria: safety, value for money, reduction of disruption and environment.

- Safety (weighting 0.2). Although a key objective of the Agency is to meet the targets given in the Strategic Plan for Safety, safety is not put in the first place because experience has shown that very few maintenance projects have a significant impact on safety. The scoring criteria are objective and initial scores are based on the class of surface deficiencies and the accident rating of the site.
- Value for Money (weighting 0.3). The weighting of 0.3 reflects the importance to the Agency of obtaining best value for money from its maintenance programme. The score is based on the Incremental Economic Indicator value of the option and reflects the total discounted saving over the analysis period.
- Reduction of Disruption (weighting 0.4). In view of current importance and to emphasize the goal of reducing network disruption, this criterion has the highest weighting of 0.4. The user costs of an option is used as a measure of disruption as this reflects the traffic volume, the works duration and the typical delay experienced by each vehicle at different times of the day.
- Environment (weighting 0.1). The environment score reflects how the project is likely to improve the environment in keeping with the Agency's Environmental Strategic Plan. An Environmental Assessment Report should be prepared at the workshop.

These clearly defined value attributes enable the scoring process of each maintenance project during Value Management workshop. The project with higher score represents higher value, thus has higher priority. There is a slight difference of how to assess the scores for different kind of maintenance project, for example, large renewal works or small ones, pavement renewals or non-pavement ones. However, they emphasize on the same four criteria for every circumstances.

The successful VM practice in maintenance domain of the Highways Agency provides guidance for the attempt in Rijkswaterstaat.

| Score Range | Justification | Criteria (and weighting factor) | | | |
|---|---|---|---|---|---|
| | | **Safety (0.2)** | **Value for Money (0.3)** | **Reduction of Disruption (0.4)** | **Environment (0.1)** EA Score from Table B6 |
| 100 | Fully justified | Substantial surface deficiencies and linked high accident rating, supported by an accident analysis. **The works address a proven accident problem (Unavoidable)** | The proposed option is appropriate for the defects and has an **IEI > 5.0 and ≤ 20 ,** compared to the *Do Minimum* option. OR: Asset is in extremely poor condition, substantial Do Minimum works and works are appropriate | Reduction of user costs **≤ 50 % and > 25%** relative to the *Do Minimum* OR: The works will remove the current need for frequent emergency and unplanned works. The works will cause negligible disruption. | Not available |
| 90 | | | | | EA score 5 |
| 80 | Good justification | Moderate surface deficiencies and linked, above average accident rating, supported by an accident analysis OR: Substantial deficiencies and average accident rating. | The proposed option is appropriate for the defects and has an **IEI > 2.0 and ≤ 2.0,** compared to the *Do Minimum* option. OR: Asset in very poor condition, significant Do Minimum works and works are appropriate. | Reduction of user costs **≤ 25 % and >15 %** relative to the *Do Minimum* OR: The works will reduce the current need for frequent emergency and unplanned works. The works will cause slight disruption. | EA score 4 |
| 70 | | | | | EA score 3 |
| 60 | Moderate justification | Moderate surface deficiencies and linked, average accident rating OR: Substantial deficiencies and low accident rating. | The proposed option is appropriate for the defects and has an **IEI > 0.5 and ≤ 2.0** compared to the *Do Minimum* option. OR: Asset is in poor condition, significant Do Minimum works and works are appropriate | Reduction of user costs **≤15 % and >7.5 %** relative to the *Do Minimum* OR: The works will remove the current need for occasional emergency and unplanned work. The works will cause moderate disruption. | EA score 2 |
| 50 | | | | | EA score 1 |
| 40 | Poor justification | Slight surface deficiencies and average accident rating OR: Moderate surface deficiencies and low accident rating | The proposed option is questionable for the defects and/or has an **IEI > 0.1 and ≤ 0.5** compared to the *Do Minimum* option. OR: Asset is in moderate to poor condition, negligible Do Minimum works and works are questionable | Reduction of user costs **≤ 7.5 % and > 2.5 %** relative to the *Do Minimum* OR: The works will reduce the current need for occasional emergency or unplanned works . The works will cause major disruption. | EA score 0 |
| 30 | | | | | EA score -1 |
| **20** | No justification | Slight surface deficiencies and low accident rating OR: No deficiencies **The works are expected to have a neutral effect on safety.** | The proposed option is unnecessary or inappropriate and/or has an **IEI >0 and ≤ 0.1** compared to the *Do Minimum* option. OR: No whole life cost analysis has been undertaken, asset condition is moderate, no Do Minimum works and the works appear to be unnecessary or inappropriate | Reduction of user costs **≤ 2.5 and > 0 %** relative to the *Do Minimum* OR: The works will have no effect on the normal maintenance regime and emergency or unplanned works are rare. The works will cause extreme disruption. | EA score -2 |
| **10** | | | | | EA score < -2 |

Table 3. Pavement small works scoring framework in the regional roads programme of Highways Agency

# 3 Case Study – Hansweert Locks

This research is an attempt of Value Methodology in maintenance domain in Rijkswaterstaat. Hansweert Locks (Hansweertsluis) is picked up as the case study. Hansweert Locks, an infrastructure asset in the NHK project, has a history of 22 years. It consists of two locks. Figure 8 shows the image. Although it is not the most complicated lock in Zeeland region, the electrical installations and some mechanical parts are very old-fashioned and can be greatly improved. Thus it is worthwhile to give some value studies on the locks with the aim of improving the value.

Figure 8. Hansweert Locks

This chapter is divided into 7 sections. The case study, named Hansweert project, follows a VM approach defined in the first section. The next four sections explain the work procedure and the results of each phase, followed up by conclusions. A section called “observation” follows up, showing all the problems that are observed during the process. Finally, the case study is concluded with improvements and recommendations which are derived for further application of VM.

## 3.1 VM Approach in the case study

As introduced in the VM Job Plan used in SAVE International (section 2.1), a complete VM Job Plan contains six phases which include information phase, function phase, creative phase, evaluation phase, development phase and presentation phase. Most effort is put in the first four phases of value job plan in the case study according to the research objectives. The way how these four phases are carried out in the case study is shown in Figure 9.

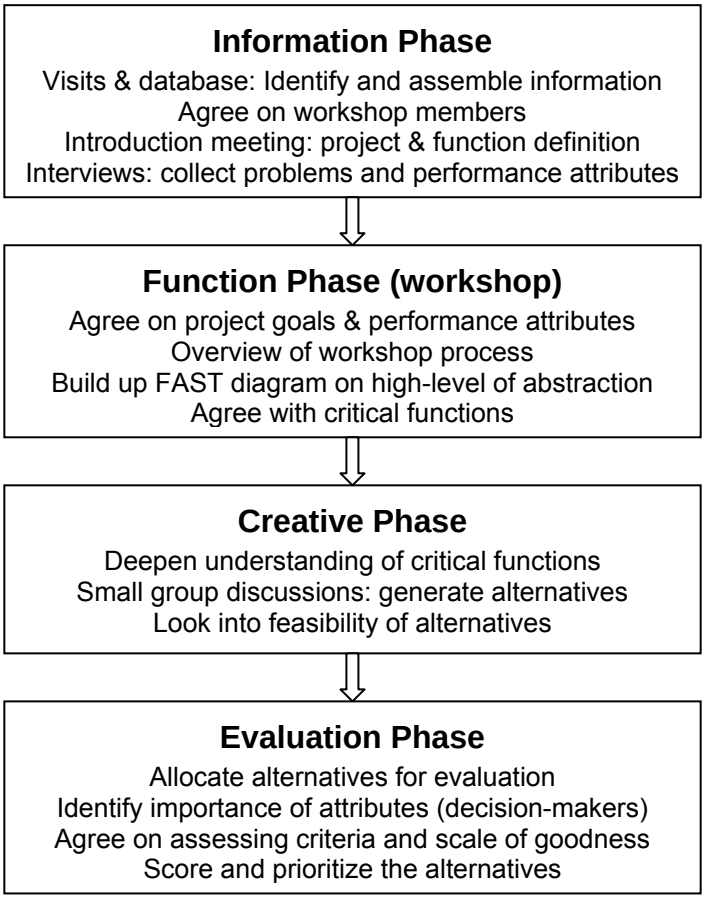



Figure 9. Value Methodology Approach in the Case Study

*Information phase*

A good start is half of the success. The objective of the information phase is to make a good preparation for the workshop session. The following tasks are fulfilled.

- **Collect project information.** It is important for the value engineer to identify and assemble information which helps to get more insight of the project, indentify project scope and participants, and prepare whatever is needed for the next steps. Tools can be site visit, database investigation, principle documents, etc.;
- **Agree on workshop members.** A multi-discipline team is one of the basic principles of VM. After the value specialist has developed a basic understanding of the project, she has to invite right people to be the value team members. What is also important, a multi-skilled facilitator for the workshop session is also invited;
- **Conduct an introduction meeting.** An orientation meeting is arranged with the purpose to introduce Value Methodology, project background, team members and most importantly the unique way of function definition which will be the common language during workshop. Before this introduction meeting, background information is sent to team members for preview. This meeting plays as the kick-off meeting;
- **Interview relevant people to collect problems and performance attributes.** Questions are asked during interviews mainly with two objectives: to make clear what the problems are and thus opportunity for improvements; to collect attributes which are important to describe performance characteristics. Records of the interviews are made.

Preparation interviews are unique comparing to most value studies. Because of difficulties to arrange group meetings in Rijkswaterstaat, individual interview is the most applicable tool to get enough information. This is the most important step in the Information Phase, not only to pre-warm the VM study but also to save time during workshop session. The information obtained from interviews is essential input of the workshop and also for evaluation phase.

*Function phase (workshop)*

Every system and activity exists for its function. The objective of function phase is to help people understand why those elements of the project exist, what is the relationship between the functions, which functions contribute most to the overall performance and cost, and which functions are not providing good value or not necessary. Function phase cannot solve problems directly but is very helpful to understand and identify critical problems. In a word, it builds up a way for solutions.

In the case study, the function phase is done within a workshop and some after-workshop discussions with these procedures:

- **Agree on project goals and performance attributes.** Project problems collected from interviews are firstly agreed by every member. The next step in the problem-framing process is the identification of goals which if achieved would evidence resolution of the problems. Besides, performance attributes derived from individual interviews are also approved by the group at the beginning of the workshop. Two of the attributes are agreed as the most important ones;
- **Provide an overview of the workshop process.** Function Analysis System Technique is an important and useful technique in VM, however, it is also the most difficult to explain, grasp and accept because of its unique way of function definition and logic direction. As a result, it is very important to present clearly in advance how this FAST diagram will be built;
- **Build up a FAST diagram on high-level of abstraction.** This is the essential task of the workshop. The facilitator guides the whole process to construct a comprehensive function diagram to gain a common understanding of the whole system and also stimulate possibilities for improvements. HOW and WHY questions are always asked. A FAST diagram created in this way not only explains the principles of the existing system but also inject new functions as possible improvements. This diagram stands on a high level of abstraction, in order team members to stimulate innovations rather than focusing too much on sub-system details. Only those critical functions need further study within small groups in the next creative phase.
- **Agree on critical functions.** The agreed performance attributes and history cost and performance data guide the sensitivity analysis to identify critical functions. Because of the time limitation in the workshop, this is done by the value engineer herself based on all the available information and discussions with team members. The objective is to find those functions which contribute most thus are sensitive to each attribute. For a maintenance project which searches for improvements, the question “Which functions if improved will result in a great improvement in the attribute?” is raised. The outcome is thus performance killers, cost drivers of the project and also some improving functions which might be built in the future.

What should be highlighted here is the process of building up the FAST diagram which follows the steps introduced by J.Jerry Kaufman and Roy Woodhead in their book “Stimulating Innovation in Products and Services with Function Analysis and Mapping”. The process starts with project problems and goals which induce a list of concerned items. By asking HOW and WHY questions, around 30 random functions are resulted. It is these random functions that initiate the construction of a FAST diagram. Team members start to think about the relationship of the random functions in HOW, WHY and WHEN direction. They can also add more functions to make the diagram logical. A FAST diagram finally comes out in a constructive and efficient way.

From the individual interviews to the logic way of constructing a FAST diagram, all the work done until now is aiming at one goal: to stimulate project members to pinpoint out critical functions which, if improved, will add value to the asset from their point of view.

*Creative phase*

After identifying the critical functions, the next question is how to improve these functions. The purpose of creative phase is to produce new ways to perform project functions with a focus on the key ones. These tasks are performed:

- **Deepen understanding of critical functions.** Because the previous function diagram represents a high level of abstraction, critical functions are first studied further in order to generate creative alternatives. Key questions are, which sub-function is exactly the cause of problem? What else can perform the same function but will not have the same problem?

- **Generate alternatives based on small group discussions.** Brain storm, as a basic technique used in generating creativity, would better be done also in a workshop. However, it takes too much time and effort, and especially difficult for the first try in Rijkswaterstaat (the reason will be explained in case study). Furthermore, people from different disciplines have different focus areas; good result could also be gained by discussions within relevant disciplines. Thus in this case study, alternatives are generated based on small group discussions;
- **Look into feasibility of the alternatives.** Alternatives should be feasible which could be demonstrated by technical experience or other similar projects.

The creative phase results in a list of feasible alternatives to improve the performance of the asset.

*Evaluation phase*

When there are several renewal and modification alternatives, how can we evaluate them and make decisions according to the budget? There is no efficient way of decision-making in Rijkswaterstaat at the moment. Decisions are usually made based on available budget, feasibility of the project, cost analysis, technical experience and sometimes gut feeling. There has been a long waiting list for years. The reasons why these projects have not been implemented are:

- Lack of budget;
- Culture of Rijkswaterstaat: the way it is now is ok! Efficiency is not a goal yet, nor a continuous improvement attitude at Rijkswaterstaat;
- Many improvements needs to be tested before widely implemented (long trajectory);
- Lack of capacity to prepare the changes;
- Most improvements are gold plated solutions at least that is the way they appear to be;
- No good analysis of the actual gains;
- A lot of people are needed to support the idea rather than a good analysis of the actual gains; again culture-related;
- The replacement works should wait for several years until the actual installation needs to be replaced. Many installations have a rather long life cycle (50-100years), so an improvement of 20 years ago might be outdated today. Replacement before end of lifetime is only done in extremely profitable situations.

All reasons can be summarized to one: lack of necessity at the moment. It often needs an external impulse to get things moving such as accident or disaster, which is not the right way of working. To achieve best value for money, a scoring framework should be developed to prioritize all these investment projects. The last step is to make decisions based on budget limitation.

This framework is developed in evaluation phase. The objective is to provide a framework for the decision-makers to evaluate and prioritize the alternatives for further development. This value based framework can also be used whenever a decision has to be made during the further phases of the project. The evaluation phase should include four missions although the case study only fulfills the first three because of information limitation.

- **Allocate alternatives for evaluation.** Different focus areas and different phases of a project may attract different interested people. That is why alternatives which meet particular needs are allocated for the evaluation process. For the case study, the main focus is the renewal and modification projects which are interesting to both Rijkswaterstaat and contractors;
- **Identify importance of attributes (decision-makers).** As stated before, “value” concept is a tradeoff between functionality and cost. In a value based decision-making framework, value attributes include both cost sorts and performance attributes. All the alternatives should be considered with respect to the value attributes. However, these attributes are not equally important. The relative importance should be identified by the decision-makers, which represents their value system. Examples can be found in table 2 and table 3 in Chapter 2. In the proposed framework in this case study, this work is done by the author based on paired comparison, which is commonly used in VM;
- **Agree on assessing criteria and scale of goodness.** Experience from the British Highways Agency tells that clearly defined assessing criteria for every attribute and a scale of goodness can help to score each alternative with less subjective opinions which make evaluation easier and more accurate. The scale of goodness defines an acceptance range of all the criteria in which 1 means acceptable and 5 represents most satisfying. A few alternatives can also be marked as “what must be done” or “what must not be done”. Attributes and scales are both project-based.

- **Score and prioritize the alternatives.** Each alternative should be scored according to each attribute. These scores multiply the importance of the attributes and the product will be the total score of an alternative. Higher score represents higher value, thus leads to a higher priority for the alternative.

At the completion of these four phases of VM, the value team should have identified a number of alternatives with their priorities, which will need to be developed into finite recommendations within budget (called change proposals in Service Provider Contract). However, the evaluation phase of the case study does not really do the evaluation but proposes a framework for evaluation. This is due to information limitation but still meet the objectives of this research.

The next four sections describe each phase in detail. The researcher works as the value engineer (VE) while Frits Willems, the supervisor of this research and a consultant of NHK project from Grontmij, works as the workshop facilitator (WF).

## 3.2 Information Phase

### 3.2.1 Work Procedure

The project schedule of this phase is listed in the table below:

| Time (Period) | Tasks |
|---|---|
| 01/03/08 – 20/03/08 | VE: Collect information about Hansweert Locks from Rijkswaterstaat: Decomposition, Drawings & Documents about working principles and site visit. |
| 20/03/08 – 07/04/08 | VE: Send invitation & background information to right people |
| 07/04/08 | VE&WF: Introduction meeting: introduce the project, team members, VM and the function analysis technique: FAST. Exercise on function definition. |
| 08/04/08 – 23/04/08 | VE: Interviews with project team members in order to give deeper understanding of the project, to collect problems on Hansweert locks and important performance attributes. The objective is to prepare and conserve time for workshops.<br><br>The following questions are asked during the interviews.<br>• What are the objects or functions that usually break down and need maintenance?<br>What is the cost to maintain these parts or replace them?<br>• What kind of preventive maintenance are taking place? Why are these activities needed?<br>What is the cost?<br>• What options can help to reduce failure and increase success?<br>• What attributes are considered to be important to describe the performance of the locks?<br>Which attributes are relatively important? |

Table 4. Schedule of Information Phase

### 3.2.2 Results

*Project Information*[28]

Hansweert Locks has two functions. The main function is to enable waterway traffic for ships and land traffic for people who live nearby. Two locks work together to enhance the capacity. Even when one lock breaks down, another lock can still perform the function. When doors are closed, walking

[28] There is no English information about Hansweert Locks at all. All the information provided here comes from general translation of Dutch documents and conversations with people who work on Hansweert Locks.

people or cyclist can cross the locks. Guiding system, traffic lights and alarms are used as traffic guidance. Another function is to stem water as a barrier to protect land from floods, which requires that for each lock one of the doors should be closed at any time.

An average of 45,000 ships pass the locks every year. This number is increasing. The average passing time is 20-30 minutes. This time will become longer due to more demands in the future.

Here is a brief introduction of working principles of the lock system.

- Operators recognize coming ship, receive contacts from the ship and take right actions. With help of a radar system, operators can easily see the locus of ships that appear nearby from a screen (Figure 10). After communications by calls and enough ships entering the right lock, operators begin to execute the lock passing process by clicking right buttons. An indicator board shows the process with red lights (Figure 11). With this board, operators can easily control the process. And when there is a problem, the board can help to find which part has problems.

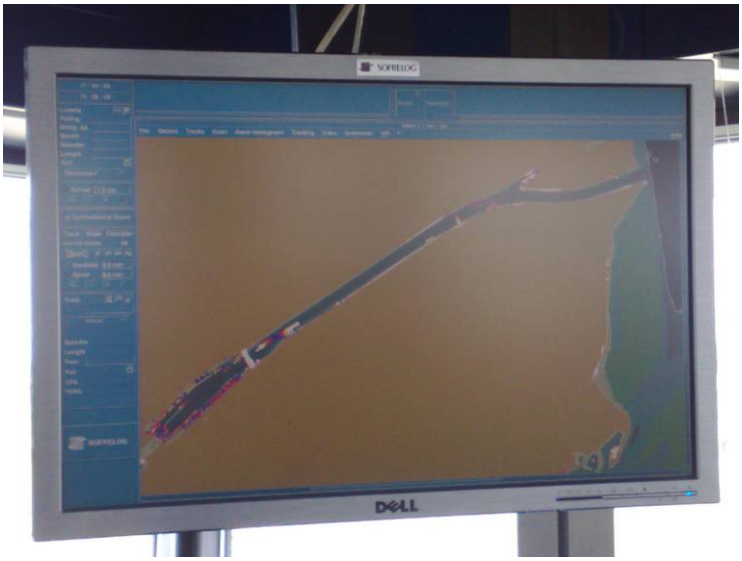



Figure 10. Ship Locus Screen

Figure 11. Ship Passing Process Indicator Board

- After operators click buttons, orders are sent to the control system - thousands of relays (See one of the relay cabinets in Figure 12). These relays control the execution of subsystems by controlling the electric current connection. Relay system is a very old-fashioned control system although it is reliable. When there is a problem, it takes time to find the right relay and fix it.

Figure 12. Relay Cabinet

- The four doors are the main civil parts which require full maintenance every 10 or 12 years by pulling the whole door out. When opening and closing the doors, they are dragged by huge steel mechanism including steel ropes, with motion provided by motors. There are five valves (Figure 13) in the door, to equal the water levels of outside and inside the tank. When the water level measuring system tells that the water levels are equal, the door can be opened. The water level measuring system works in very old-fashioned way, by measuring the air pressure. Picture can be seen in Figure 14.

Figure 13. Door with five valves (underwater)

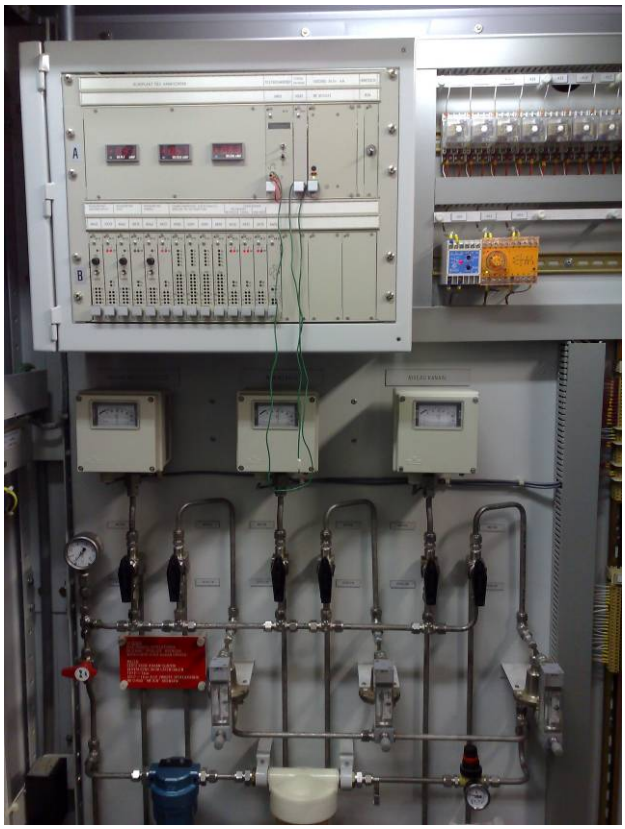


Figure 14. Old-fashioned water level measuring system

- The service principle is first come first serve. Normally until there are four or five ships coming into the tank will the operators execute the ship passing process. See Figure 15.

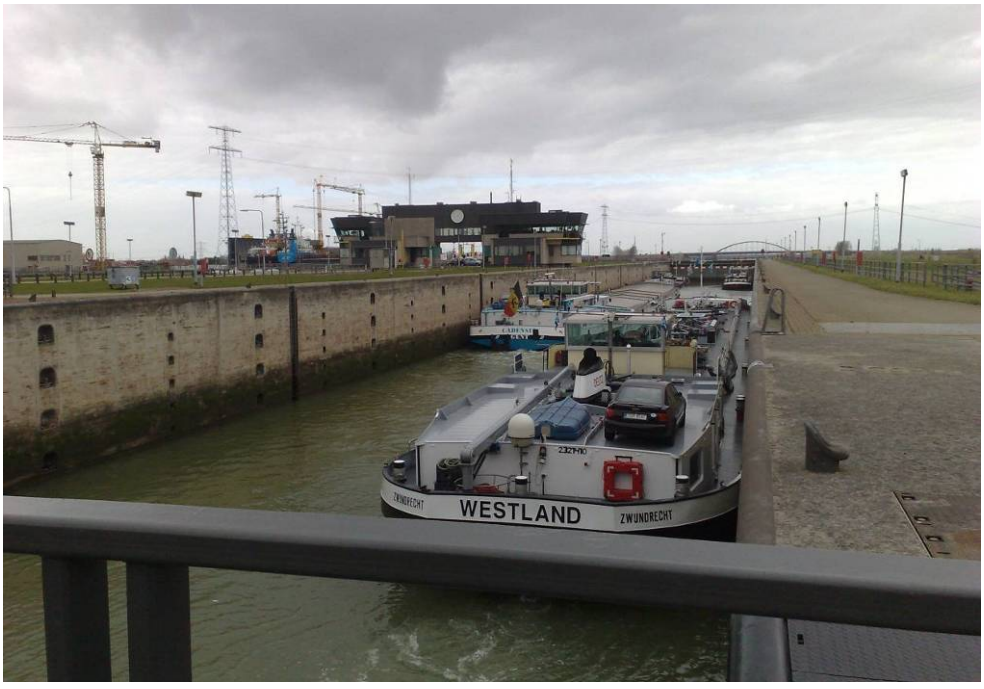



Figure 15. Ships Waiting in the Tank

Rijkswaterstaat contracts out all maintenance activities of Hansweert Locks to different contractors but keep maintenance planning, operations and customer service in house. People who are working in civil, mechanical and electrical disciplines make their own plans for the next years based on inspection report, their own experience and advice from manufacturers. Discussions among different disciplines are needed because of overlapping of their maintenance activities. Group discussions

are also required when there is a need for replacement projects. Large replacements should be proposed to the infra-provider in Zeeland region, who will make decisions whether and when the projects will be carried out.

Inspections and planned maintenance are done by contractors who only carry out the required tasks. Besides, when corrective maintenance is needed, operators or inspectors in Rijkswaterstaat just call the particular contractor and fix the problem. Contractors should provide 24 hours' service and a quick response of the emergency problems.

There are hundreds of scanned drawings for Hansweert in the database, but it is very difficult to find the right one. What is more surprising, there is no digital database of maintenance history. Although they keep everything on paper, it is very difficult to collect information from it. They do not have a database that shows how often the relay system breaks down, what the cost is and how long the downtime lasts. But they know how to maintain their installations since they work on them for many years. This is called EXPERIENCE.

*Team Members*

The proper value team should consist of 6-10 people from different disciplines. Here is the list of people who are invited to interviews and workshop.

- Henk Aarnoutse - Project leader in Rijkswaterstaat of Hansweert locks maintenance project;
- Kees Steenepoorte - Person in Rijkswaterstaat who is in charge of maintenance plan of Hansweert locks and familiar with maintenance costs;
- Charles Mollet - Technical person in Rijkswaterstaat who is familiar with decomposition and principles of the locks;
- Ger Duerinck - Technical person in Rijkswaterstaat specializing in mechanical installations of the locks;
- Wies de Blok - Technical person in Rijkswaterstaat specializing in electrical installations of the locks;
- Harry Karelse - Operator of the locks who works on site on daily base;
- Bram Baas - Inspector from Rijkswaterstaat who is in charge of maintenance operation;
- Jan Bosland - Advisor for infra-provider who can represent infra-provider from Rijkswaterstat.

*Interviews*

Interview minutes are recorded in **Appendix B**.

Formal interviews and informal talks show that people from different disciplines look into their own responsibilities. They have different opinions on improvement and performance attributes. They look at problems from different aspects. Conclusions about problems and performance attributes can be drawn which will guide the workshop process.

The most important performance attributes are collected from the interviews[29]:

- Availability, for ships to pass by.
- Safety, for ships and people, and also for protecting the land from flood.
- Reliability, for frequency of failure.
- Fitness for future, for a long term solution.
- Environmental burden, for people living nearby and ecology.

The main problems of Hansweert Locks are:

- Old-fashioned electrical relays and switches break down often. This is a major cause of failures.
- Valves break down more often now because of: rise of water level, friction and fatigue.
- Poles (barrier for cyclist) do not work quite often.
- Water-level measuring system break down more and more often, because of failure in electrical installations.
- Different life spans of civil, mechanical, electrical parts cause maintenance problem. Efficiency can be improved by cooperation.

[29] These attributes are general ones collected from individual interviews. They will be discussed during workshop and accurate definitions will be given later.

- Communication between three parties-contractors, operators and customers-are not sufficient.

People from different disciplines have different suggestions of improvements. Those include, steel beams constructed before doors; doing maintenance together; making engines for valves higher or upgraded; replacing relay system with PLC system; more preventive maintenance; more inspection; more advanced technology used; more communication with customers to know their needs.

### 3.2.3 Conclusions

A lot of work has been done before workshop session, as shown in the procedure and results. It takes much time to get necessary information and to make people aware of the project. Valuable conclusions and guidelines can be drawn from the preparation work:

- Preparation interviews are helpful to search for right workshop members. So the list of people changes when the process is going on. For example, the first few interviews tell that more failure happens in electrical installations, thus more electrical engineers should be invited to interviews to identify the problems.
- Many project members think that more communication between maintainers, operators and customers will make better performance. Interviews also show that, different life cycles of civil, mechanical and electrical parts causes problem especially in preventive maintenance. These ideas support the multi-disciplinary approach of Value Methodology. People from different disciplines should cooperate and think on a higher level.
- Problems locate not only on technical aspect but also activity aspects. There are many possible improvements on operational level, for example, more communication, more process information collected, and less failure reaction time. Thus we should not only take technical functions into the scope of FAST but also work processes[30]. In a word, a FAST diagram on a high-level of abstraction may help to understand the project better. This changes the original idea of making a technical FAST diagram.

## 3.3 Function Phase

### 3.3.1 Work Procedure

The workshop was arranged in the afternoon of 24th of April. Table 5 shows the planned schedule.

| Hour | Tasks |
|---|---|
| 1st | Interview conclusion: agree on attributes & problems of Hansweert Locks<br>Set project goals: what does the satisfying performance look like?<br>Select important performance criteria |
| 2nd | Select and Expand Random Functions<br>Construct a FAST diagram on high level of abstraction |
| 3rd | Adjust the FAST diagram |
| 4th | Sensitivity analysis: critical functions<br>Brainstorm Improvements |

Table 5. Planned Workshop Schedule

Eight out of planned ten people participated in the workshop. They are Frits Willems, Jan Bosland, Henk Aarnoutse, Kees Steenepoorte, Wies de Blok, Harry Karelse, Ger Duerinck and Xiaowei Li. Disciplines include value engineer and facilitator, infra-provider, operator and technical people specializing in civil, mechanical and electrical installations.

To wait until more people presented, the workshop started almost one hour late thus lasted for three hours. The workshop fulfilled the task of the first two hours in the work plan and also stimulated brainstorming on how to improve some important functions. Figure 16 and 17 are two pictures from the workshop.

[30] VM is commonly applied in process studies, as introduced in section 1.3.1. Besides, several FAST examples analyzing product processes can be found in J.Jerry Kaufman and Roy Woodhead's book: *Stimulating Innovation in Products and Services with Function Analysis and Mapping*. See references.

Figure 16. Workshop in Progress


Figure 17. Constructing FAST Diagram

After the workshop, the value engineer adjusted the rough FAST diagram made in the workshop and gave a sensitivity analysis based on all the information from interviews, workshop and after-workshop consults.

### 3.3.2 Results

*Performance Attributes*

These attributes are agreed as important ones to describe the performance of the locks:

- **Availability:** availability means the ability for ships to pass by. Thus only when both of the locks are shut down, the availability is lost. Both planned and unplanned unavailable hours should be considered. It shows the disruption of the traffic.
- **Ship Passing Time:** the total time from ships getting close to the locks until they pass the locks and continue their journey. We should record the average passing time of a certain period (e.g. a

year). This criterion reflects both planned and unplanned downtime of one lock and operating efficiency of ship passing process.

- **Safety:** safety is the condition of being protected from accidents that may cause health or economical losses. Safety of both shipping traffic and land crossing traffic are included. Cause of real accidents and potential threat should be taken into consideration.
- **Reliability:** reliability is the ability of the lock system to perform its required functions under stated conditions for a specified period of time. While availability and ship passing time represents number of failures and time to repair, here reliability implies frequency of failures by calculating Mean Time Between Failure. A lock system is not reliable if it breaks down too often although every failure may only take ten minutes.
- **Maintainability**: maintainability refers to the ease and probability of carrying out required maintenance tasks, including corrective maintenance and preventive maintenance. It answers the questions, whether the maintenance is easy to be carried out or not, how long a problem is solved and whether there are enough technical support personnel to debug or perform root cause analysis in pursuit of solving a problem.
- **Environment:** environment refers to the extent to which all the maintenance activities result in a sympathetic approach to the environment, measured by local and global impact, the energy consumed through use and other "green" issues such as water pollution and fish migration.

It is also agreed in the workshop that availability and ship passing time are the most important attributes.

*Project Goals*

The overall objective of the project is to improve the performance of Hansweert Locks within budget. By asking question what a successful performance looks like, the answers represent some concrete project goals which identify the stakeholder's needs.

- Reliable water leveling system.
- Reliable control system.
- Robust water level measuring device.
- Integration the electrical, mechanical and civil maintenance activities.
- Adequate communication between operators, maintainers and lock user community (captains of the barges and residents living near the lock).
- User friendly presentation of the "water picture"[31] to the operators enabling a safer operation of the locks and a shorter training period of new lock operators.
- Reliable barriers.

*Random Functions*

In order to emphasize on the problem-related functions and make route for a project FAST model, the work begins with randomly selecting important items and functions of interest. The functions selected are then expanded to add dependent functions (HOW direction), independent functions (WHY direction) and "how to improve" functions. By brainstorming on "how to improve" functions, stakeholders' needs are recognized and creativities are stimulated as well. Table 6 shows the random functions.

| Item | Why function | Function of Interest | How function | How to Improve Function |
|---|---|---|---|---|
| Lock | Reach destination | Guide Shipping | Pass ships | Improve Availability |
| | Protect land | Stem water | Close door | |
| | Enable Road Traffic | Guide road traffic | Close door | Enhance Safety |
| Water Leveling System | Ensure Safety | Equal Water Level | Control Flow | Improve Traction |
| | | | Measure Water Level | Collect Water-level Information |

[31] A water picture presents an overview of all traffic in the shipping lanes.

| Item | Why function | Function of Interest | How function | How to Improve Function |
|---|---|---|---|---|
| Control System | Give Orders | Control Ship Passing Process | Control Current | Renew Control Infrastructure |
| | | | | Add Logging Function |
| Maintenance | Ensure Availability | Prevent Hindrance | Plan Maintenance | Integrate EMC[32] Activities |
| | | | Inspect Installations | |
| | | Correct Hindrance | Identify Problem | Collect Process Information |
| Communication | Plan Route | Enable Communication | Inform Ships | Transmit Shipping Information |
| Operation | Enable Lock Passing | Operate Lock | Click Button | Present Shipping Overview |
| | | | | Shorten Learning Curve |

Table 6. Expanding Random Functions

[32] EMC activities represent activities in Electrical, Mechanical and Civil disciplines.

*Rough & Adjusted FAST Diagram*

When an adequate number (around 30) of expanded list functions have been identified, the FAST model-building process can start. Figure 18 shows the rough diagram resulted from the workshop.

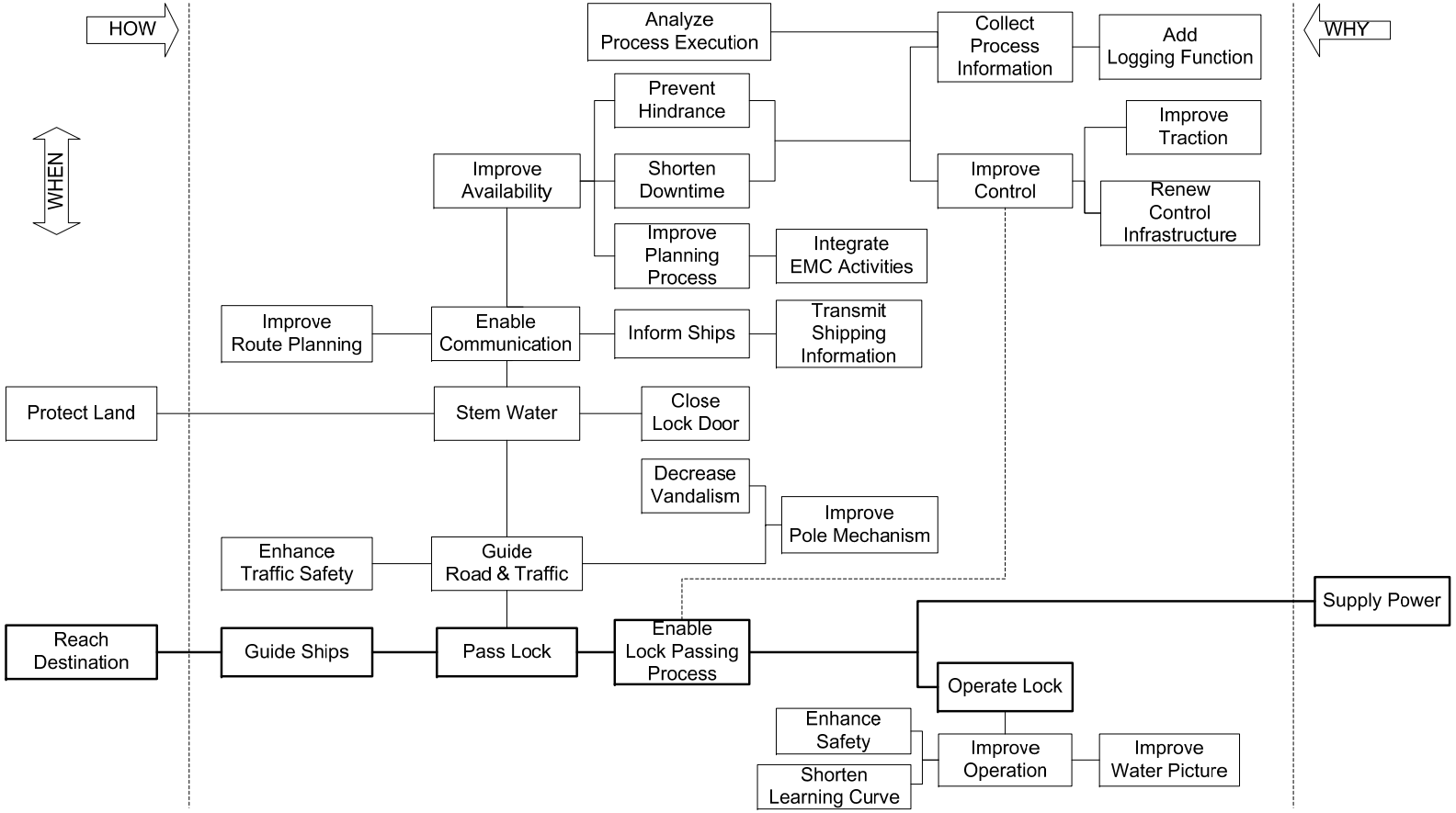
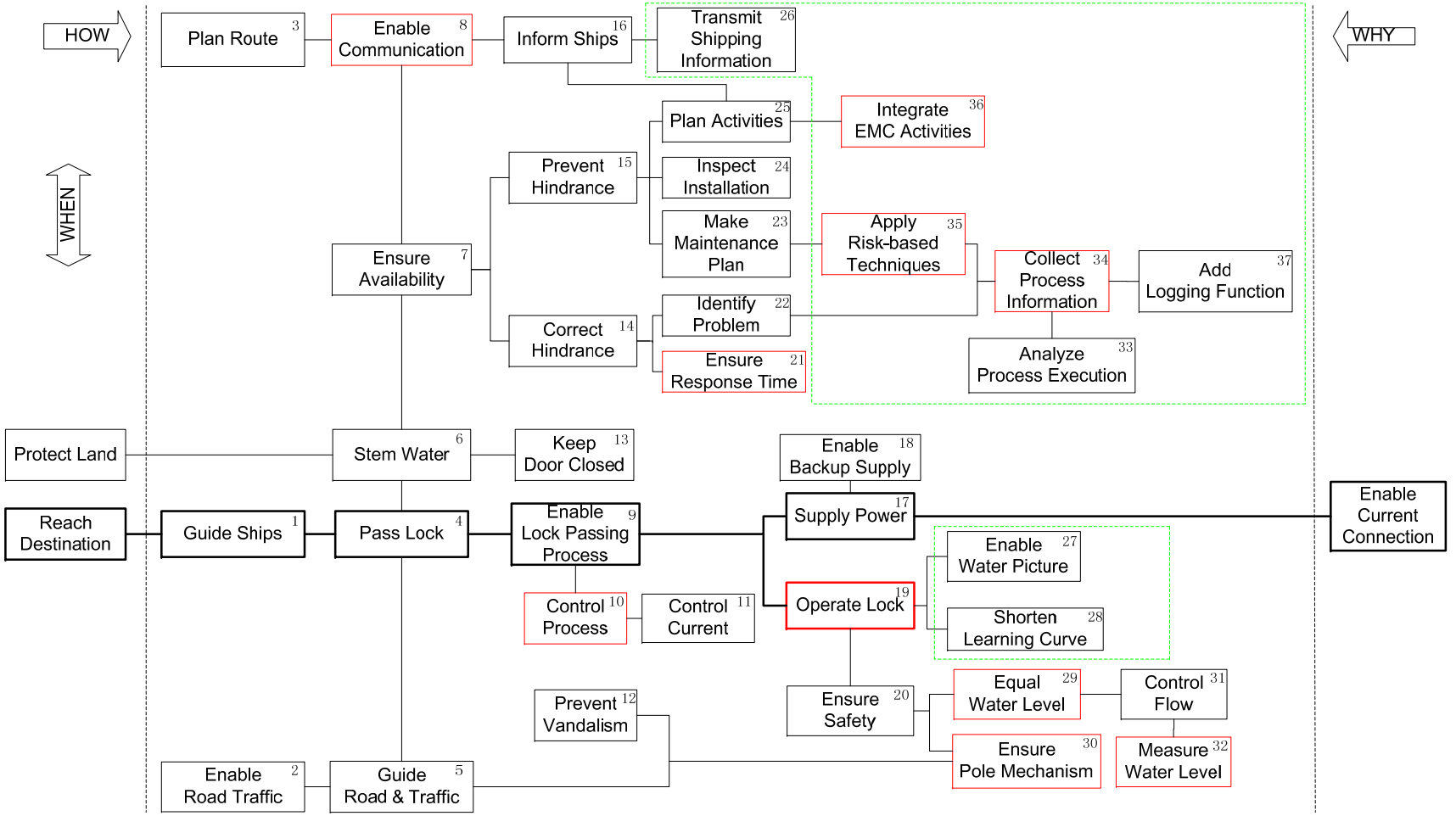



Figure 18. Rough FAST Diagram

During the workshop, people had so much motivation on improvements that this rough FAST diagram mainly emphasizes on improving functions. Most technical problems are not explicit. This is not sufficient to identify critical technical problems. As a result, adjustments should be made, as seen in the figure in the next page. The functions in the green box are the ones that do not exist at the moment but are worth being developed.




| Functions significant to Performance Attributes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | Functions significant to Performance Attributes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ship Passing Time | | | | | | | | X | | X | | | | | | | | | X | | X | | | | | | | | X | X | X | X | | X | | X | | Ship Passing Time |
| Availability | | | | | | | | | | X | | | | | | | | | | | X | | | | | | | | | | | | | X | | | | Availability |
| Safety | | | | | | | | | | | | X | | | | | | | X | | | | | | | | | | | X | | | | | | | | Safety |
| Reliability | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | X | X | | X | | X | X | | | Reliability |
| Maintainability | | | | | | | | | | X | | | | | | | | | | | | | | | | | | | X | | | | X | | | X | | Maintainability |
| Environmental Burden | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Environmental Burden |

Figure 19. Adjusted FAST Diagram and Sensitivity Analysis

*Sensitivity Analysis*

The performance attributes, as introduced before, are identified by the project team. Among those attributes, availability and ship passing time are considered to be the most important ones. By asking "Which functions if improved would contribute most to each attribute", a sensitivity analysis on performance can be carried out (Figure 19). Those functions, which have great influence on the performance attributes especially availability and ship passing time, are regarded as critical functions in performance respect.

Cost is also an important issue in the concept of value. Table 7 lists some electric maintenance works with their prices per year where contract represents contracts for inspection and preventive maintenance[33].

| COST | Contract | Corrective Maintenance | Repair & Materials | Total |
|---|---|---|---|---|
| electrical maintenance | € 250.000,00 | € 50.000,00 | € 50.000,00 | € 350.000,00 |
| some small contracts | € 50.000,00 | € 5.000,00 | € 5.000,00 | € 60.000,00 |
| air / central heating | € 25.000,00 | € 5.000,00 | € 2.500,00 | € 32.500,00 |
| generator and fuel | € 25.000,00 | € 5.000,00 | € 5.000,00 | € 35.000,00 |
| radar | € 10.000,00 | € 5.000,00 | € 2.500,00 | € 17.500,00 |
| cctv | € 10.000,00 | € 2.500,00 | € 2.500,00 | € 15.000,00 |
| marine telephone | € 7.500,00 | € 2.500,00 | € 2.500,00 | € 12.500,00 |
| telephone | € 1.000,00 | € 0,00 | € 0,00 | € 1.000,00 |
| burgling and fire | € 1.000,00 | € 500,00 | € 0,00 | € 1.500,00 |
| dc-power supply | € 2.000,00 | € 500,00 | € 500,00 | € 3.000,00 |
| risk/profit contractor | € 25.000,00 | € 1.500,00 | € 7.500,00 | € 34.000,00 |

Table 7. Maintenance Works and Prices

This table clearly shows that those contracts covering all inspection, preventive maintenance work and service time cost most. Information from previous interviews (Appendix B) tells that situations are the same in civil and mechanical area. To make a better preventive maintenance plan, "Integrate EMC Activities" and "Apply Risk-based Techniques" functions become critical.

In Figure 19, critical functions are highlighted with red color.

### 3.3.3 Conclusions

A multi-discipline workshop was successfully carried out at the beginning of function phase. Although it only last for three hours, valuable results were derived from the workshop. A list of project goals were agreed which implied possible improvements; some demands were explicitly laid out such as enabling communication with customers and collecting process information; some improvements were also recommended, for example enabling water picture for operators, transmitting information for customers, adding logging functions and so on. In a word, the workshop session not only enables the share of common understanding among different disciplines but also stimulate people to pinpoint out functions which have potential to add value.

However, critical functions are pointed out mainly based on experience instead of data. There is a serious lack of useful information within Rijkswaterstaat. A lot of numbers and specifications are kept on paper, but the question is what information is most useful and should be collected? This question can be partly answered by the function phase. Useful information for the function phase includes: 1) All technical failures and accidents due to technical problems in the last two or three years which have impact on the availability and ship passing time. Allocate the causes to each sub-system; collect the data of the downtime, delay hours, number of delayed ships and consequence of accidents. 2) All maintenance costs on those sub-systems which break down quite often. Costs

[33] This table is provided by an electrical engineer Jemmy Westweer, drawn from several cost tables in his database. As maintenance work is outsourced to several contractors by fixed price and Rijkswaterstaat did not keep the record of maintenance, they do not have a clear table that shows the accurate cost of maintaining every installation.

include preventive maintenance cost, inspection and corrective maintenance cost (calculated by working hours) and cost on new materials. 3) A survey of customer satisfaction.

## 3.4 Creative Phase

### 3.4.1 Work Procedure

As pointed out in Figure 19, there are ten critical functions that can be developed into alternatives or even robust options. These ten functions (with their numbers in Figure 19) can be classified into several focus area and developed within different group discussions, as shown in Table 8.

| Focus Area | Function (Number) | Discussion Group (VE Exclusive) |
|---|---|---|
| Maintenance problems on strategic level | Collect Process Information (34)<br>Integrate EMC Activities (36)<br>Apply Risk-based Techniques (35) | Jan Bosland & Arno Dobbelaar:<br>Advisors of infra-provider who can represent management level. |
| Maintenance problems on technical level | Control Process (10)<br>Equal Water Level (29)<br>Measure Water Level (32)<br>Ensure Pole Mechanism (30) | Henk Aarnoutse, Wies de Blok & Jemmy Westveer: Technical people in mechanical and electrical disciplines. |
| Customer Service | Enable Communication (8) | Eric Luca:<br>Traffic manager of Rijkswaterstaat Zeeland |
| No need for discussion[34] | Ensure Response Time (21)<br>Operate Lock (19) | |

Table 8. Critical Function Classification

Creation is based on a deeper understanding of the problem. Key questions are, which sub-functions are the ultimate causes of the problem? What else can perform the same function but will not result in the same problem? To realize the function, what other functions should be supportive? Alternatives are finally generated with a reference to experience and other similar projects.

### 3.4.2 Results

Some functions are related to each other and analysis on them can be combined.

*Collect Process Information & Control Process & Measure Water Level*

Two kinds of process information are demanded to be collected: process-control information from the control system and water-level information from the water-level measuring system. However, the problem is that the working principles of both systems are too old-fashioned that they cannot record process information. Figure 20 shows the relationships of the three critical functions.

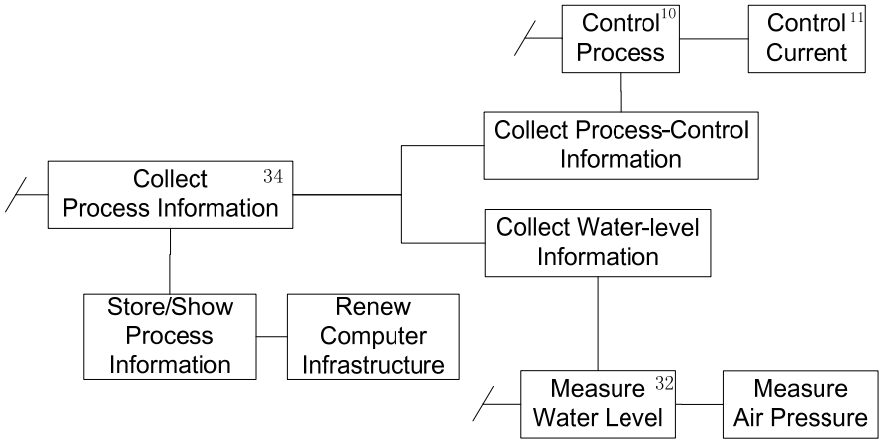



Figure 20. How to Collect Process Information

[34] These two functions are relatively simple and have been discussed during previous phase.

Alternatives are:

- Replace the relay system with PLC (Programmable Logical Circuits). PLC system controls the ship passing process by software programmes. It can collect control information and transmit it to host-computers. Although it requires a large investment (about 1 million euro), the work will reduce inspections, preventive maintenance, corrective maintenance and most importantly failure rate.
- Install SCADA (Supervisory Control And Data Acquisition) system. SCADA system can receive information about movements of the doors from the PLC system and monitor the speed of the doors. When there is a problem with the door, operators and maintenance staff can easily identify the problem the correct them.
- Replace current water-level measuring system with an electronic one. The new system can record water-level information and present to operators any time. The information can also be used in data analysis, for example, rising sea level. Furthermore, the electronic system is able to "talk" with the PLC system well.

*Integrate EMC activities & Apply Risk-based Techniques*

The electrical, mechanical and civil activities were separated because they were outsourced to different contractors. This causes a lot of disturbance for the operators. But now, as one contractor takes the job, it is possible and more convenient to integrate the three types of activities.

Furthermore, a FMECA based RCM approach is under pilot within NHK project. This systematic approach is very helpful to identify and plan all maintenance activities especially in inspection tasks and periodical preventive maintenance. Thus it combines both of the functions. However, the problem of RCM is, it goes too much into details and requires a lot of working hours. Besides, maintenance history data should also be gathered to support the method.

So the alternative is: applying RCM approach to develop an optimal maintenance program.

*Equal Water Level*

The working principle of the valve system is studied in detailed FAST diagram as shown in Figure 21. There are two main causes problems located in the two critical functions, as shown in red.

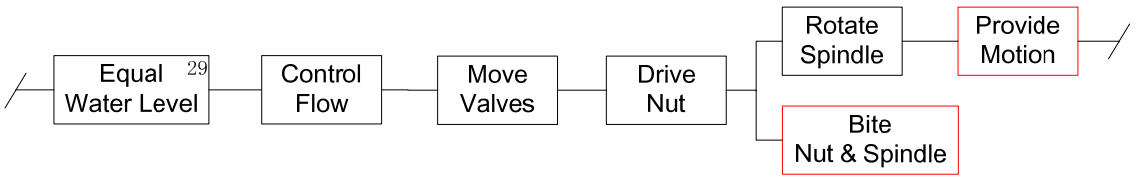



Figure 21. Detailed Function Analysis of the Valve System

Problem 1: sometimes the motor for the function Provide Motion is under water. However it is not so water-resistant which cause problem in the function of Provide Motion. A picture taken during site visit shows that the water level has ever risen to the height of the motor. Pay attention to the wall in Figure 22.

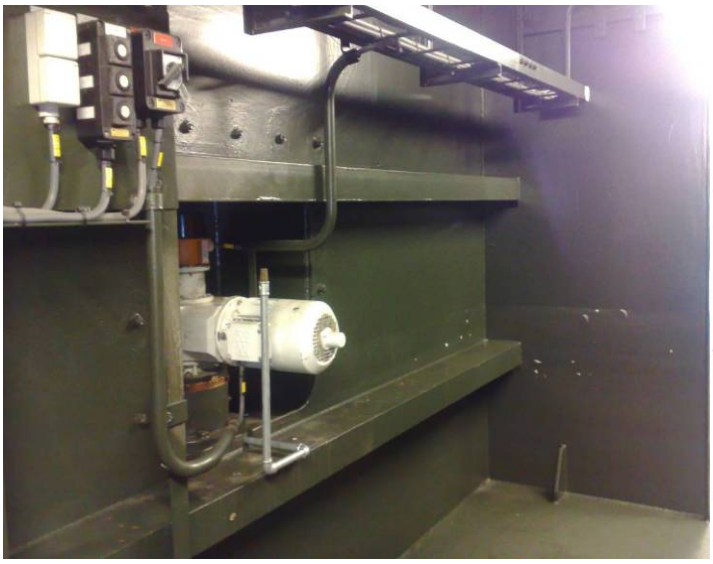


Figure 22. Motor Influenced by Water Level

Problem 2: the valve system follows a traditional mechanical principle. The motion provided by the motor is transmitted from the spindle to the valve by a lubricated bite between the nut and spindle. Problems usually happen within the bite because of friction and also fatigue as shown in Figure 23.

For the first problem, solutions might be either building a water-resistant cover for the motor or reconstructing the motor to a higher level. For the second problem, it can only be temporary solved by preventive or corrective maintenance; that is to replace the spindle or replace some parts around it when they expire which can not solve the problem in the long term. To completely solve the problem, one question should be asked: How can we avoid the mechanical bite while still being able to drive the valve?

In Grevelingensluis and Bergsediepsluis, another two locks in Zeeland region, a hydraulic system was introduced. This system drives the valves by pressure instead of the mechanical system. What is more encouraging, it can also solve the motor problem because a motor is not even in need any more.

So the alternative is, to build a hydraulic system for driving the valves. There are 25 valves in Hansweert. A new system can be installed depending on the expiration time of the current system.

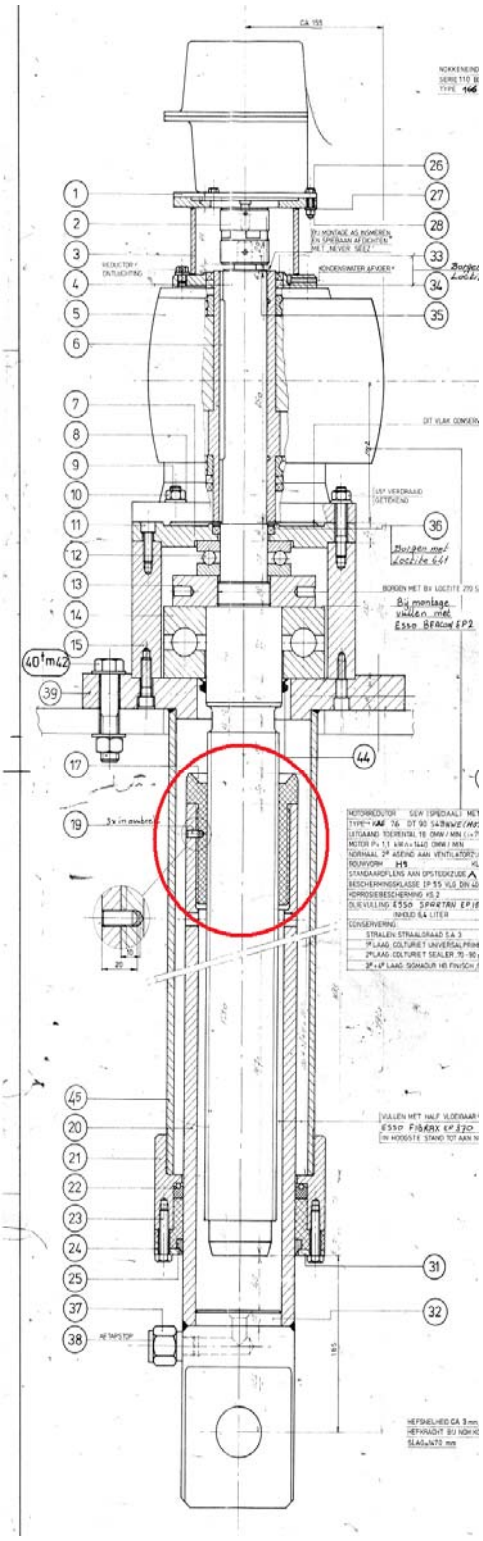


Figure 23. Valve System

*Ensure Pole Mechanism*

The problem of poles comes from electrical installations, which is very common also in other locks. Rijkswaterstaat is developing a central control system for all the poles in a project called MOBZ project. Although Hansweert is not included now, the new technology can also be applied on Hansweert if it works well.

So the alternative is: central controlled poles.

*Enable Communication*

As service provider concept becomes widely adopted within Rijkswaterstaat, almost all the project members have pointed out that more importance should be attached to communication between operators, maintenance contractors and customers. Maintenance activities which will influence the availability and ship passing time should be informed to the ships in advance. (This has been done by Rijkswaterstaat.) It is also recommended that the traffic information should also be transmitted to the captains in order them to make good plan of the journey.

Now there are not many traffic jams on Hansweert Locks, but on the other lock called Krammersluis, delay happens quite often and sometimes it may lasts 10 hours which causes serious economic loss for particular companies. According to the traffic manager Eric Luca, the number of ships from Rotterdam to Anterwerp may double within 10 years. At that time, Hansweert Locks will also face the same problem.

One possible alternative is resulted by asking “how to transmit shipping information”. “By placing electric information boards near the canals that inform captains what route is the quickest and/or how long the delay will be entering a lock because of high traffic.” This is similar to signals on highways. The digital board might also show the views of surroundings which could also improve aesthetics although it is not considered as one of the important value attributes in this project.

Another alternative may be, to collect customers’ data and travel information in order to plan shipping route for them. This requires good cooperation from customers. They should have the willingness to provide some private information and should not complain if the principle of “first come first serve” is broken. The feasibility has to be studied by surveys and law consultation.

To sum up, two alternatives are created: information boards and route planning.

*Ensure Response Time & Operate Lock*

Alternatives were generated in previous phases about these two functions:

- Ensure 24 hours’ service and half an hour’s response time.
- Install more cameras to provide better water picture for operators.
- Shorten learning curve for operators.

### 3.4.3 Conclusions

Some alternatives are resulted from the creative phase based on group discussions. From the contractors’ point of view, alternatives about maintenance include:

- Replace the relay system with PLC system.
- Install a SCADA system.
- Replace current water-level measuring system with an electronic one.
- Apply RCM approach to develop an optimal maintenance program.
- Build a hydraulic system for driving the valves.
- Control poles centrally.

With respect to Rijkswaterstaat, alternatives concerning the customer service and operation are:

- Install more cameras to provide better water picture for operators.
- Shorten learning curve of operators.
- Install information boards and transmit shipping information.
- Collect shipping information in order to plan route for ships.
- Ensure 24 hours’ service and half an hour’s response time when outsourcing maintenance.

Part of the creative phase shows that FAST technique can be used at different levels of abstraction. HOW questions are used to give deep insight of the critical functions and search for solutions. Causes of problems are identified and relationships between the functions are recognized. If

problems have to be solved while there is no experience in similar situation, the function analysis technique will be even more helpful to create bright ideas based on brainstorming.

## 3.5 Evaluation Phase

Although the previous phases result in many alternatives concerning all preservation aspects, only renewal and modification projects are taken into consideration in the evaluation phase of the case study following the demand of Rijkswaterstaat and the objective of this research. This evaluation phase, as explained in section 3.1, aims at helping the decision-makers within Rijkswaterstaat to develop a decision-making framework based on VALUE concept which can be used to evaluate all the modification proposals and make decisions. Different from previous phases, this section directly introduces a value-based decision-making framework for the case study. Recommendations are then given for further application of this framework in other projects. Finally, further discussions are presented.

### 3.5.1 Proposed Decision-making Framework

Renewal and modification projects are those projects which require an initial investment during preservation phase of the system, in order to reduce annual maintenance/operational costs and/or to increase the performance of the assets on RAMSSHE (Reliability, Availability, Maintainability, Safety, Security, Health and Environment). Take the alternative “replacing the relay system with PLC system” for example. The project asks for a high investment but would reduce maintenance cost and improve availability, reliability and maintainability. Some projects would not reduce maintenance/operational cost but still have the value on RAMSSHE. So how can we judge which projects represent more value to the client?

The proposed framework starts with a definition of client’s value system. Here the client is Rijkswaterstaat. For maintenance investment projects, important attributes include cost sorts and performance attributes. Relative importance is compared and results in weight factors for each attribute. The next phase is to identify assessing criteria and scales of goodness for all the attributes based on which alternatives can be scored. Higher total score represents higher value and higher priority. Decisions can be made finally according to budget limitation.

The next four sub-sections show how decision-making work can be done in the case study.

*Value Attributes*

A value attribute, in the market, is a range of inherent characteristics of a product that affects its value perception in the eyes of customer. For infrastructure projects, value attributes are defined by asset owner which allows him to compare the effects of various solutions and make a decision.

During previous interviews before the workshop, these questions were asked frequently: What attributes are important for the performance of the Hansweert locks? Which ones of them are relatively more important? During the workshop session, performance attributes were agreed. As defined, value is a tradeoff between cost and performance. So all the cost sorts and performance attributes should be added together as the value attributes for the Hansweert Locks:

- **Investment:** investment here includes all costs associated with renewals or reconstruction regarding to the maintenance and upgrading of the locks, including procurement, engineering and installation cost.
- **Maintenance cost:** maintenance cost refers to all costs associated with the maintenance implications of the completed locks. In this case study, only electrical and mechanical installations are considered.
- **Availability:** availability means the ability for ships to pass by. Thus only when both of the locks are shut down, the availability is lost. Both planned and unplanned unavailable hours should be considered. It shows the disruption of the traffic.
- **Ship Passing Time:** the total time from ships getting close to the locks until they pass the locks and continue their journey. We should record the average passing time of a certain period (e.g. a year). This criterion reflects both planned and unplanned downtime of one lock and efficiency of executing ship passing process.

- **Safety:** safety is the condition of being protected from accidents that may cause health or economical losses. Safety of both shipping traffic and land crossing traffic are included. Cause of real accidents and also potential threat should be taken into consideration.
- **Reliability:** reliability is the ability of the lock system to perform its required functions under stated conditions for a specified period of time. While availability and ship passing time represents number of failure and time to repair, here reliability implies frequency of failures by calculating Mean Time Between Failure. A lock system is not reliable if it breaks down too often although every failure may only take ten minutes.
- **Maintainability**: maintainability refers to the ease and probability of carrying out required maintenance tasks, including corrective maintenance and preventive maintenance. It answers the questions of whether the maintenance is easy to be carried out or not, how long a problem is solved and whether there are enough technical support personnel to debug or perform root cause analysis in pursuit of solving a problem.
- **Environment:** environment refers to the extent to which all the maintenance activities result in a sympathetic approach to the environment, measured by local and global impact, the energy consumed through use and other "green" issues such as water pollution and fish migration.

*Client Value System*

Only the value attributes are not enough to describe the client's value system. When a client is looking for a new house, he may consider many attributes such as price, area, outlook, comfort, size of the garden and transportation convenience. But what attributes are more important in the client's eyes, aesthetics or size? For how much more is he willing to pay for a bigger house? A lot of such questions can make explicit the relative importance of the value attributes which help to identify a client value system.

Paired Comparison Analysis is chosen as a team orientated technique to differentiate between attributes. It is commonly used in defining the client's value system accurately[35]. This technique compares the importance of the attributes relative to each other, in order to derive the relative weights. Finally it results in a value attribute matrix (as seen in Figure 24). It is particularly useful where there is not enough objective data. In product market, only the customer representatives may speak during this process. But in infrastructure projects, it is better for the asset owner and traffic manager to determine the relative weights based on their attitude and investigation of the users.

The process for implementing the Paired Comparison Analysis involves the following steps:

- **Label the value attributes:** List all the value attributes in the matrix and label them as A,B,C…H.
- **Discuss pairs:** Compare attribute A with attribute B asking, "Which of the two attributes is more critical in satisfying the project's objectives and demands?" Enter the answer in the intersecting box of A and B. Then ask another question, "How much is the value advantage to improve this attribute, small, moderate or significant?" Enter the corresponding number in the same box. Continue for all pairs with the same questions until the matrix is completed.
- **Total scores:** Add the number for each attribute. For some cases, one of the attributes will receive no points. This does not mean this attribute is not important, but implies that improving this attribute will not lead to much value improvement for the project.
- **Normalize scores:** Calculate percentages for each attribute, round off as needed.

This process results in relative weights for all the attributes. In VM approach, this work should be done in primary phase of function phase by discussion during workshops. However, as the two key attributes were identified during workshop, detailed comparison could be postponed until the evaluation of alternatives.

Since all the attributes are important to the success of the maintenance for the locks, it may be difficult to compare the importance of the attributes. The decision-makers should think in this way: which attribute requires more attention comparing to the other ones and what is its importance to

[35] References: Robert B. Stewart, *Fundamentals of Value Methodology*, Xlibis Corporation, 2005
John Kelly, Steven Male, Drummond Graham. *Value Management of Construction Projects.* Blackwell Publishing, 2004
J.Jerry Kaufman and Roy Woodhead, *Stimulating Innovation in Products and Services: With Function Analysis and Mapping,* John Wiley & Sons, 2006

the customers/users: in other words, given the state of Hansweert Locks today, which attributes, if improved, would lead to greater value.

Attributes, such as security and energy consumption, are also important. However, they are not included in the list of important attributes. This does not mean these attributes have no value, but simply means that an improvement in these attributes is not considered as being able to yield significant value for Hansweert Locks.

Keeping the concept of improvements in mind, decision-makers can give scores. The figure below shows the opinion from the value engineer, based on her discussions with technical people and the traffic manager in Rijkswaterstaat.

| | B | C | D | E | F | G | H | Description | Score | Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| A | B3 | C1 | A1 | A2 | A2 | A2 | H1 | Investment | 7 | 15 |
| | B | C2 | D1 | B2 | F1 | G1 | B2 | Maintenance Cost | 7 | 15 |
| | | C | D1 | C1 | C1 | C2 | C2 | Availability | 9 | 20 |
| | | | D | D2 | D1 | D2 | D2 | Ship Passing Time | 9 | 20 |
| | | | | E | F1 | E1 | E3 | Safety | 4 | 9 |
| | | | | | F | F2 | F2 | Reliability | 6 | 13 |
| FACTOR | | | | | | G | G2 | Maintainability | 3 | 6 |
| 1 Small value advantage | | | | | | | H | Environment | 1 | 2 |
| 2 Moderate value advantage | | | | | | | | Total | 46 | 100 |
| 3 Significant value advantage | | | | | | | | | | |

Figure 24. Paired Comparisons

There are some more considerations based on which the comparisons are given:

- As agreed by all team members, availability and ship passing time which relate directly to the service to the customers are considered to be the most important attributes. During the conversation with the traffic manager Eric Luca, he showed his serious worries about providing services to the customers. A delay often causes much economic loss, let alone a shut down of the entire waterway. Different from road traffic, there is usually less or no alternative route to go on waterways. Considering public value, a choice can be made between cost and improvement of the performance;
- Thinking in a long term, maintenance cost savings should be much more important than initial investment;
- Although safety is a key objective of Rijkswaterstaat, experience has shown that very few maintenance projects have a significant impact on safety. It should be considered during design of the locks. Of course safety can always be improved by better operation and installations;
- In contrast with safety, reliability is a big issue that maintenance improvements can address. Furthermore, it is rather important for infrastructure assets to be reliable, thus reliability counts much;
- Environment cannot be ignored when cheaper material might result in negative environment impact even though it saves money.

*Scoring Framework*

During previous workshop phase, engineers proposed some alternatives regarding to renewals of certain parts of the locks. Those include:

- Replace old-fashioned relay system to PLC system;
- Build up SCADA system to collect process information;
- Replace old air pressure water-level measuring system with new electronic one;
- Build up a hydraulic system for valves;
- Control poles centrally.

All these projects require investment but result in benefits in other aspects. How to determine the prioritization of the projects in order to make decisions? The answer from VM is, by scoring each alternative based on the value system derived.

For each attribute, we can build up a scale of goodness and score from 1 to 5. 1 means acceptable and 5 means most satisfying or unavoidable. In order to give scores based on objective data, assessing criteria should be identified for each attribute.

- **Investment:** In order to compare in the same time scale, the analysis period should be the same for all projects. The Present Value of the project cost is taken as the assessing criterion.
- **Maintenance Cost:** Total annual maintenance cost for electrical and mechanical installations is taken as the assessing criterion. The difference between annual maintenance cost before and after the renewals and modifications implies maintenance cost savings of the projects;
- **Availability:** Both planned and unplanned unavailable hours of the locks per year is used as the assessing criterion;
- **Ship Passing Time:** This attribute is not only controlled by maintenance but also greatly influenced by operation and traffic control centre. Thus maintenance should not take all the responsibility. To evaluate the maintenance impact on this attribute, delay hours × ships due to technical problems should be calculated as the assessing criterion;
- **Safety:** Although number of accidents or injuries might be the best criterion to evaluate safety on a higher level, it is not applicable for maintenance projects because one improvement will not definitely eliminate one accident. But maintenance projects may have significant improvements on safety by solving existing safety problems or reducing the risk of safety problems. The safety improvements that a project brings can be used in the assessing process.
- **Reliability:** Mean Time Between Failure is used to assess the reliability. There are three failure categories: significant, major and minor failure[36]. All these failures should be taken to account.
- **Maintainability:** Preventive maintainability for all kinds of failure is greatly reflected in maintenance cost. So a good way to assess the attribute is Mean Time To Repair for all failures;
- **Environment:** The project's impact on environment helps to assess this attribute.

Table 9 proposes a scoring framework of renewal and modification projects on Hansweert Locks. In some cases, alternatives can be "Must Do Option" or "Must not Do Option". The scales of goodness are based on information from technical people and an educated guess. This table only gives guidance on how to score each attributes for every alternatives. If time permits, decision-makers should be involved to make an accurate range of the goodness.

[36] Reference: EN50126. *Railway applications - The specification and demonstration of RAMS*, September 1999

| Attributes (weighting factor) | Assessing Criteria | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Investment (15%) | Investment in 10 years (Million €) | (0.8, 1.0] | (0.6, 0.8] | (0.4, 0.6] | [0.2, 0.4] | <0.2 |
| Maintenance Cost (15%) | Annual Cost (Million €) | (1.5, 1.6] | (1.4, 1.5] | (1.3, 1.4] | [1.2, 1.3] | <1.2 |
| Availability (20%) | Unavailable Hours / year | (100, 120] | (80, 100] | (60, 80] | [40, 60] | <40 |
| Ship Passing Time (20%) | Delay hours × ships | (160, 200] | (120, 160] | (80, 120] | [40, 80] | <40 |
| Safety (9%) | Safety Improvements | The project is expected to have a neutral effect on safety | In the middle of 1 & 3 | The project will improve an existing safety problem, or remove a high risk of safety problem. | In the middle of 3 & 5 | The project solves a proven accident problem. (Must Do Option) |
| Reliability (13%) | MTBF (hours) | (60, 90] | (90, 120] | (120, 150] | [150, 180] | >180 |
| Maintainability (6%) | MTTR (hours) | (8, 10] | (6, 8] | (4, 6] | (2, 4] | <2 |
| Environment (2%) | Environment Impact | The project has a negative impact on the environment. (Must not Do Option) | In the middle of 1 & 3 | The project will have a neutral effect on the environment. | In the middle of 3 & 5 | The project will have a strong positive impact on a clearly defined environment problem. (Must Do Option) |

Table 9. Scoring Framework for Hansweert Case Study

*Decision Making*

In order to give scores to all the assessing criteria based on facts, a list of information, which should be prepared before scoring each alternative, can be derived:

- Investment cost of the new project, life span of the new system;
- Annual maintenance cost of the new system, maintenance cost on other parts which will be influenced by the project;
- Failure rate, MTBF, MTTR of the new system;
- Safety report of Hansweert Locks which addresses safety problems and risk of safety problem in last year;
- Environment report showing the environment burden and problems at the moment. Environment assessment report or other document showing environmental factors have been considered.

Information for the new system can be gathered from other applications or from manufacturers.

With the information, scores can be given for each attribute of each project. These scores multiply the weight factors of the attributes and the product will be the total score of an alternative. The yellow part in Table 9 represents the current situation (Do Minimum Option) as an example. The total score for the Do Minimum Option is:

$$15\%\times5+15\%\times1+20\%\times1+20\%\times2+9\%\times1+13\%\times2+6\%\times2+2\%\times3=2.57$$

Higher score represents higher value, thus leads to a higher priority of the alternative. Projects with higher priority within budget can be put into the plan for next stage.

### 3.5.2 Recommendations for Other Projects

The framework proposed for the case study is project based. Other projects can also follow the process and define their own framework.

For similar projects on locks, the same attributes may be used, but each project will have unique characteristics which will change the ranking of the attributes relative to that similar, but not the same, project situation. For example, for Hansweert locks, safety is not a major problem, thus it has relatively lower weight. However in other locks which have been reported with serious safety problems, safety should have a much higher importance and more effort should be contributed to improve this attribute.

For projects on other kinds of assets such as bridges, highways and buildings, value attributes may vary much. Aesthetics, security and energy consumption may be taken as important attributes. And the weight factors will change too. This is due to the change of clients' value system which will influence the scoring process and final decisions. Value Methodology aims at creating solutions which will improve the overall value for clients based on their demands and value system.

### 3.5.3 Discussions on the Framework

*Further studies of the framework*

Rijkswaterstaat is a budget oriented organization, thus there should be some place to make a tradeoff between investment and performance improvements. The proposed framework, if well defined, can provide sensitivity scenarios. For example, for € X, Y amount of reliability can be improved. Or Y amount of availability improvement requires X amount of money. This gives a guideline for Rijkswaterstaat to determine their level of service based on the limited budget, which is useful when outsourcing maintenance by a Service Level Agreement.

However, this is based on an accurate definition of the goodness of all attributes. Rijkswaterstaat should be able to answer these questions: What is the acceptable level of performance of the object/waterway? And what is the most satisfying level? How much are you willing to pay to reach that satisfying level? The proposed scales of goodness (mostly linear) in Table 9 are defined by the value engineer based on her educated guess and all the information she got from technical people

in Rijkswaterstaat. Although it has been discussed with a person at management level[37] who showed his affirmation, the process could be greatly improved if more people were involved and management commitment is required.

Furthermore, the definition of value system and the assessing criteria may help to identify KPI's (Key Performance Indicators) for a Service Level Agreement in which a certain service level is required. Possible performance indicators for the contractors are: unavailable hours for the whole waterway, ship passing delay hours × ships, MTBF, MTTR, reaction time, number of injuries/casualties due to lack of maintenance. Based on the scale of goodness and budget, Rijkswaterstaat can try to derive the KPI requirements.

*Comparison to the one used in Highways Agency*

The decision-making framework proposed based on value concept is similar to the Value Management scoring framework used in British Highways Agency as described in Section 2.2.2. There are two main differences:

- Highways Agency uses the same value system for all the maintenance projects while the proposed one in this research is project based. Attributes and relative weights may vary for different projects. This is due to different situations and requirements in different projects.
- Highways Agency combines all cost sorts (initial investment and whole life cost of maintenance) into one attribute: value for money, by assessing the Incremental Economic Indicator of different alternatives[38]. By contrast, investment and maintenance cost savings are separated attributes in the proposed framework mainly because Rijkswaterstaat takes different actions in accountancy about investment cost and maintenance cost and they should count as different attributes in the value system when making decisions.

*Comparison to financial decision-making tools*

When seeking for a method to judge investment alternatives, one might quickly comes out with some techniques on financial basis, especially the use of financial evaluation methods of investment and exploitation costs (Net Present Value, Internal Rate of Return, etc.) However, they are not very applicable in this case because the benefit of a renewal project usually contains performance improvement which is difficult to be monetarized in Rijkswaterstaat. Financial evaluation techniques are very useful when the return of a project can be calculated easily, for example, the use of LED (Light Emitting Diode) lights instead of bulb lights which results in longer life span, lower energy consumption and less maintenance. However, it is not applicable to transfer -ability improvements into money. Rijkswaterstaat only applies a financial decision-making tool called OEI (social cost-benefit analysis) on new construction projects. But they seldom do this in maintenance projects.

By contrast, the proposed framework based on Value Methodology aims at making the clients' value system explicit in order to seek equaled value to the clients. These attributes are not assessed by amount of money but by its own scale of goodness which makes it more applicable and acceptable.

## 3.6 Process Observation

While the last four sections describe all the work procedure and technical results of the case study, this section is going to conclude observations of the process, mainly about the problems and opportunities for improvements.

- One of the main research problems is language obstacle. The value engineer (the researcher of this thesis) is an English speaker while some of the technical people in Rijkswaterstaat do not speak English. This to some extent influences preparation work and workshop. During information phase, the value engineer provided English information about VM and FAST, however, this is meaningless to those team members who only speak Dutch. All the information is transmitted through formal conversations by translation and within limited time, which is insufficient preparation for the workshop. Furthermore, the value engineer has not been involved much in the Dutch workshop. It would be better that value engineer could stay as spectator and control the whole procedure without

[37] Arno Dobbelaar: advisor for infra-provider of Rijkswaterstaat Zeeland, employee of Rijkswaterstaat.
[38] Reference: *Value Management of the Regional Roads Programme*, Highways Agency, January 2006.

being influenced by the flow of thinking in the project. For example, people emphasized much on improvements during the workshop which is good for creativity. However, when the critical technical problems are hided, people would not understand basically why these problems occur and what their relationships are.

- Another research problem is, it is such a difficulty to arrange a workshop within Rijkswaterstaat especially in the case that this work, for a student's thesis, is not their daily business. First, it is so difficult to choose a workshop time. Almost all the people related needed to be invited and asked to agree on a time. It is even more difficult to include all the disciplines. Second, although a lot of preparation had been done to invite and inform every participant, not everyone came at last and only two technical people were on time. Thus all the tasks afterwards were fulfilled within small group (normally three) of discussions.
- Not every team member is active to express his opinions during the workshop. First, this depends much on people's characters. Those active people's ideas sometimes become dominant while others' are hided. Second, not every employee in Rijkswaterstaat is aware of the changes that are taking place in the organization. They still concentrate on their own technical business. As a result, they have little interest in the workshop which aims at improvements or they could not catch up with the group's thinking. More effective teamwork could be achieved by more stimulation in preparation phase. And more workshops may also help.
- Technical people in Rijkswaterstaat are very knowledgeable and experienced about the installations of infrastructure assets, but they keep the knowledge in head. There is a lack of useful information during the whole VM process, especially when choice should be made during function phase and evaluation phase. However, VM can help to identify necessary information.
- People in Rijkswaterstaat trust each other's experience so much that little challenge is given on gut feeling. If an experienced engineer says the maintenance project will cost 1 million, nobody is going to doubt it or check it (actually it is difficult to check it because no database tells the cost). And there is nobody who might ask, if we only have 0.8 million, what can we get? People are not aware of these kinds of improvements, which kills more success from value studies.

## 3.7 Case Review

Following a proposed Value Methodology approach, the four-month case study on Hansweert Locks has brought a lot of fruitful results. The project started with gathering as much information as possible; problems were then identified and understood through function analysis during a workshop; critical functions were pinpointed out and further studied which resulted in many alternatives; finally a decision-making framework has been developed to prioritize all the maintenance improvement projects.

In the last section, an observation of the process points out many problems according to which improvements can be identified for further VM applications:

- Two actions should be taken to improve the preparation work. First, Dutch information of Value Methodology should be provided, introducing the basic concept, job plan and the benefits of VM to project members. In a word, more information should be given to attract attention and interests. Second, more support should be gained from management level. Project managers should be presented in the kickoff meeting, to identify the overall objectives of the project and stimulate team effort. This is more applicable in a real project which demands value improvements.
- Two workshops should be arranged for the function phase. The first one is similar to the one in the case study. The aim is to identify project problems, goals and demands of clients. A FAST diagram should be roughly made to gain more insight of the whole project. From this workshop, the needed information should be agreed by the team members. The tasks of gathering all the information should be allocated to appropriate people. After some time, all project members should come back for another workshop with all information available. During this second workshop, sensitivity analysis ought to be carried out based on these data or reports, in order to pinpoint out critical functions. During both of the workshops, value engineer has to be involved in controlling the progress and sometimes guiding the way of discussion.
- The decision-making framework should be defined by decision-makers and requires management commitment. Another workshop should be arranged within which enough information is provided in order to make prioritize all the alternatives based on facts.

All these improvements results in an improved VM approach which will be useful for further applications of VM in identifying maintenance improvements, as shown in Figure 25.

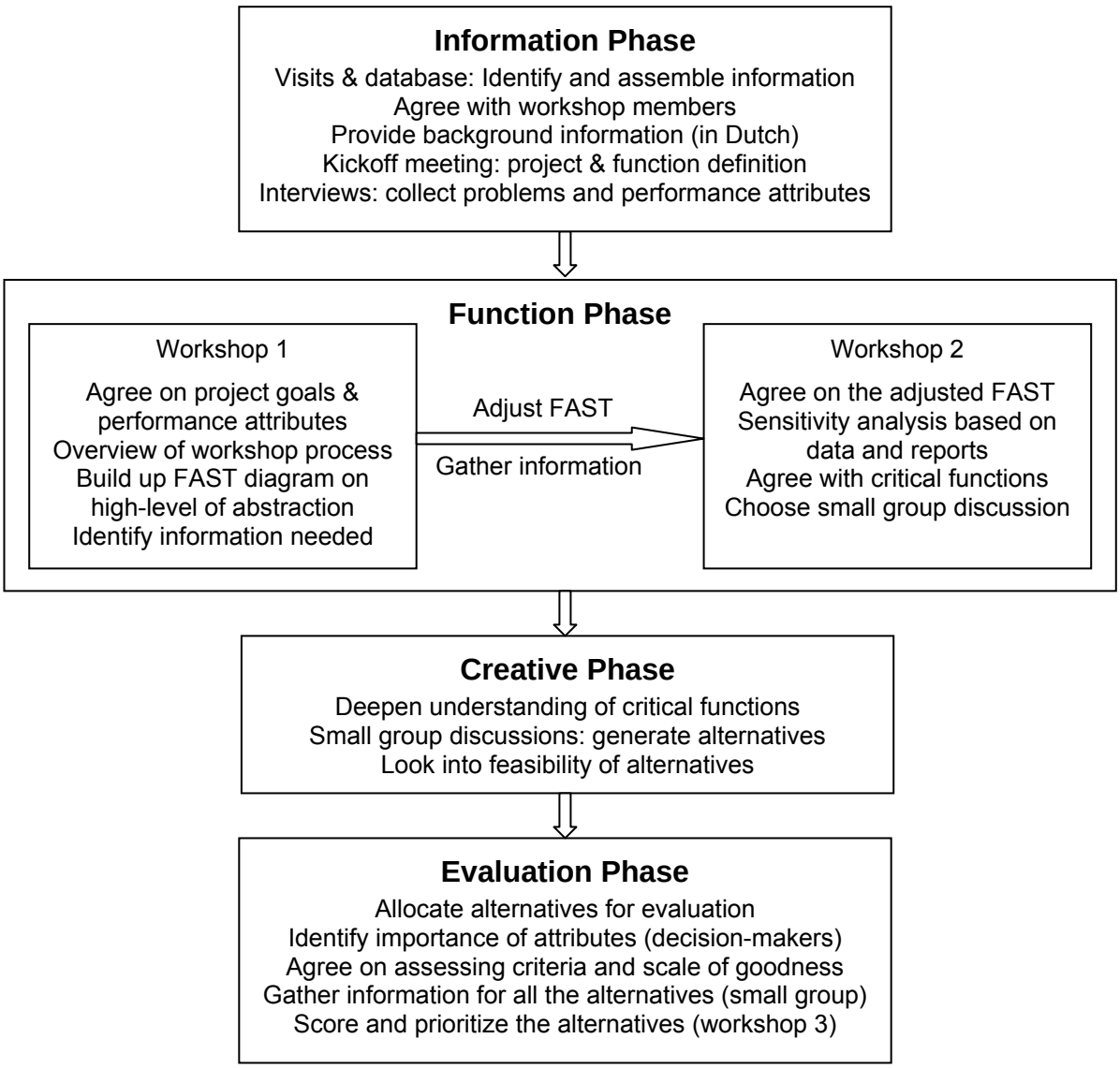



Figure 25. Improved Value Methodology Approach

A successful implementation of this approach requires several conditions which include team cooperation, available information and “stick to facts” attitude. Only when these criteria are meet that a good and effective value study can be carried out within Rijkswaterstaat.

*Team cooperation*

A good value study depends much on enough cooperation from the whole team. To stimulate maximum team effort, three key factors are demanded: enough support from management level; good communication between value engineer and team members; and a multi-skilled workshop facilitator to encourage expressions of ideas.

*Available Information*

What needs to be highlighted here is all the information that should be presented in the workshops. For workshop 2:

- All technical failures and accidents due to technical problems in the last two or three years which have impact on the identified important attributes, for example, availability and ship passing time in the case study. Allocate the causes to each sub-system; collect the data of the downtime, delay hours, number of delayed ships and consequence of accidents;

- All maintenance costs on those sub-systems which break down quite often. Costs include preventive maintenance cost, inspection and corrective maintenance cost (calculated by working hours) and cost on new materials.
- A survey of customer satisfaction.

For workshop 3:

- Investment cost of the new project, life span of the new system and discount rate;
- Annual maintenance cost of the new system, maintenance cost on other parts which will be influenced by the project;
- Failure rate, MTBF, MTTR of the new system;
- Safety report of studied objects which addresses safety problems and risk of safety problem;
- Environment report showing the environment burden and problems at the moment. Environment assessment report or other document showing environmental factors have been considered.

However, it is not easy to gather all the information at the moment within Rijkswaterstaat. Maintenance history is kept on paper which is difficult to be assorted, while information of the new investment projects is only located in people's head. The channels to collect the required information are listed below:

- Maintenance history data can be obtained from Maintenance Management System (MMS) which Rijkswaterstaat is trying to build with the help of contractors. The pilot NHK project started half a year ago. As a result, useful maintenance history information of NHK project can be derived from the MMS within a year or two. It takes time to expand to all other objects;
- Preventive maintenance and inspection costs is easy to collect from annual maintenance plans while cost of corrective maintenance can be calculated by working hours and cost on new materials. These cost data were kept by Rijkswaterstaat in the past, but will be kept by contractor in the future when Service Provider Contractor is applied;
- A survey of customer satisfaction is provided by the Dutch organization for ships called Schuttervaer. But this is an organization for professional shipping in which recreation ships are not included. To hear more voice from customers, user panels can be organized periodically;
- Rijkswaterstaat can only provide safety report for each asset from the view of protecting land. This report considers water level and weather conditions. But there is no safety report or risk manual showing safety problems and risks from the view of protecting travelling people and workers on the assets. Environment assessment report on particular objects is also missing. This should be developed in the future.
- About new investment projects, currently there is no database showing the life cycle cost of the projects and the potential performance after execution of the projects. These data can be roughly got from manufacturers and a database should be built. Furthermore, many modification projects have been executed in other regions of Rijkswaterstaat and information can be shared with help of a mature MMS which still takes much time.

*"Stick to facts" attitude*

In a good value study, each choice during the process should be made according to data and facts instead of experience or intuition only. Although experience is rather important, a good decision should base on supported facts. Because of the information shortage, people within Rijkswaterstaat trust each other's experience so much that little challenge is given on gut feeling. Value Methodology searches for a way to make decisions as objective as possible. It is recommended to ensure the scoring process auditable and evaluate how well that information supports the proposed projects. "Stick to the facts" attitude should be emphasized.

# 4 Discussion

This chapter discusses the answers to the research questions and solutions to the research problems. Finally, cost and benefit of Value Methodology within Rijkswaterstaat is discussed.

## 4.1 Answers to the Research Questions

- How can VM be used on existing objects in identifying maintenance improvements?

  This question implies two sub-questions: how can VM be used on improvements identification and how can it be used on existing objects?

  To identify improvements, the first step of VM is to recognize client's needs for function. It is always believed in VM world that clients require functions rather than objects. There may be many ways to perform the function and VM does not cut the creativity. If "Shorten Ship Passing Time" is the most important need, then problems which have serious impact on ship passing time will be identified and analyzed through their functions. These functions are addressed as critical functions and require further studies. The second step is thus to find how to realize the needed functions or to improve the critical functions. Usually alternative improvements are created by brainstorm within groups of experts. To sum up, VM process identify improvements by encouraging project members to attach value to functions, and pinpoint out those functions, if improved, will bring more value from the clients' point of view.

  Function Analysis System Technique, which is a powerful technique in VM, is commonly used for analysis of production process. For existing objects, FAST technique can also be used to understand their working process by asking HOW and WHY. It provides the way of understanding the system and activities around the system, and locating critical functions in order to stimulate improvements. The construction of FAST diagram is very flexible. High level of abstraction and lower level can be used depending on project stage. In the initial phase a high level diagram is built to recognize client's needs and understand the system on a high level. For further analysis, detailed technical FAST can be used.

- What does an adequate decision-making picture on renewal and modification projects look like based on VALUE concept?

  The procedure to develop a decision-making framework can be found in Evaluation Phase of the case study (Section 3.5). Client's value system should be firstly made explicit. For preservation phase of systems, important attributes include cost sorts and performance attributes like RAMS. Relative importance is derived and weight factors are determined for all the attributes. The next phase is to identify assessing criteria and scales of goodness for all the attributes based on which alternatives can be scored. Higher score represents higher value and higher priority. Decisions can be made finally according to budget limitation.

  This framework enables a trade-off among investment and benefits including maintenance cost savings and performance improvements, which is helpful for Rijkswaterstaat as a budget-oriented organization. Besides, it avoids monetarizing those –ability attributes, which is adequate and applicable for Rijkswaterstaat.

- Can VM be well implemented in Rijkswaterstaat? (Does it fit in the culture? Does the decision made by VM fit in the budget?)

  The result gained from the case study tells that, VM can be implemented in Rijkswaterstaat. And as the decision-making framework is based on budget, it has no problem with budget. However, a lot of problems during the case study also show that it still takes time to implement the approach well due to the culture of the organization.

  First, the success of a value study depends much on the attitude of the whole project team. However, not every employee in Rijkswaterstaat is aware of the changes that are taking place in the organization. They still concentrate on their own technical business. As a result, they have little interest in the workshop which aims at improvements or they could not catch up with the group's thinking.

Second, the biggest problem now within Rijkswaterstaat is that they do not have enough databases from which they can derive useful information. Most of the information provided by the project team comes from experience. However, this is not sufficient for an effective value study. A good sensitivity analysis during function phase and a successful scoring process should be guided by data and reports which clearly define problems.

Last but not least, because of the information shortage, people in Rijkswaterstaat trust each other so much that little challeng is given on gut feeling. Although experience is rather important, a good decision should base on supported facts. “Stick to the facts” attitude should be encouraged.

A lot of problems are observed from the case study and the improved approach with three success factors at the end of the case study (Section 3.7) addresses the main problems. If the approach is followed and the success requirements are met, Value Methodology can be well implemented and will be useful for Rijkswaterstaat and future contractors in identifying and making decisions on maintenance improvements.

## 4.2 Solutions to the Research Problems

Two main research problems were stated at the beginning of the research:

- For Contractors: how to look at the black box of maintenance and identify improvements to reach optimum cost effectiveness on the maintenance of infrastructure assets?
- For Rijkswaterstaat: In the near future, the contractor will submit their maintenance change proposals including renewal and modification projects, but there is no efficient way of decision-making for Rijkswaterstaat at the moment.

This research seeks for solutions based on the proposed method – Value Methodology. A case study is done within Rijkswaterstaat disregarding contractors because of two reasons. First, the contractor was not selected and involved in NHK project yet when the case study began in March 2008. Second, the maintenance planning work is still done by Rijkswaterstaat himself before the execution of the new contract; technical people in Rijkswaterstaat can take the place of the future contractor during the case study.

However, when the new Service Provider Contract (SPC) is executed in the future, both of Rijkswaterstaat and contractor have to participate in the VM process. The cooperation between the two parties varies in different stages of the contract.

*Starting phase of SPC*

At the beginning of the contract, the contractor is not familiar with the objects and there is not enough maintenance history information available either. Technical people in Rijkswaterstaat keep the knowledge in their heads and they are willing to share. At this stage, value workshops can help to share common understandings among people from both parties, about the system and the way of working.

The value team members should include: EMC technical people from both parties, the project manager from the contractor, operators from Rijkswaterstaat, a traffic manager or customer service group members from Rijkswaterstaat and decision-makers from Rijkswaterstaat. Value engineer may come from either party or from a third party.

To identify maintenance improvements and make decisions, the team must go through the tailored VM approach (Figure 25) step by step. People from Rijkswaterstaat, who are more familiar with the objects than contractors, should help to build up the FAST diagram and do the sensitivity analysis based on their experience. People from the contractor have the potential to inject new ideas and stimulate innovations.

The contractor is responsible for generating technical alternatives in the creative phase, while Rijkswaterstaat needs to identify the value attributes, the relative weights and assessing criteria in order to guide a decision-making process. The value engineer, who is keeping the process going, might be the most appropriate one to evaluate the VM process.

Following a VM approach, the contractor is able to identify valuable improvements and these alternatives can be evaluated during workshops according to a value-based decision-making framework.

*Mature phase of SPC*

The mature phase of SPC is one or two years after starting of the contract when the contractor has become familiar with the infrastructure assets and has collected enough information based on the Maintenance Management System.

The only difference from the early phase is, EMC technical people from Rijkswaterstaat do not need to participate in the value workshops during mature phase of SPC, since technical people can think independently based on enough information they have. But operators, traffic managers and decision-makers from Rijkswaterstaat still need to be present, in order to represent voice of the customers somehow and express their demands when making a high-level abstracted FAST.

To conclude this section, VM workshops make both parties work together and provide a discussion platform, during which maintenance improvements are identified and evaluated. Following the constructive VM process, both parties solves their problems, with help of VM techniques such as FAST, sensitivity analysis, brainstorm and decision-making framework based on value concept.

## 4.3 Cost & Benefit of Value Methodology in Rijkswaterstaat

For Rijkswaterstaat, the cost of a value study mainly comes from human resource cost for participation and training or consultant fee of value engineers. The benefits when applying VM in preservation phase of infrastructure assets in Rijkswaterstaat include:

- VM provides a constructive way of identifying improvements during preservation phase of an infrastructure asset. The process helps to identify project problems and client's needs, and also stimulates innovations.
- VM develops an adequate decision-making framework for evaluation of maintenance investment alternatives (section 3.5).
- Value workshops enable communication between Rijkswaterstaat and the contractors, and sometimes help with knowledge transfer if necessary.
- VM helps to pinpoint out information that is needed during maintenance. A list of necessary information is identified in section 3.7.

These benefits, which are not directly translated in money though, are valuable for Rijkswaterstaat especially in this exploration period.

# 5 Conclusions and Recommendations

This chapter presents the main conclusions and recommendations of this research on application of Value Methodology in maintenance domain in Rijkswaterstaat. Please note most of detailed conclusions have been discussed in section 3.7 and Chapter 4. So section 5.1 only provides general conclusions with references to previous parts of the report. In section 5.2, recommendations for Rijkswaterstaat and further research are given.

## 5.1 Summary and Conclusions

This research starts with a literature study and interviews with value specialists, in order to get more insight of Value Methodology and its applications on infrastructure assets. A four months' case study in Rijkswaterstaat is carried out following a proposed Value Methodology approach which has brought a lot of fruitful results. The project started with gathering as much information as possible; problems were then identified and understood through function analysis during a workshop; critical functions were pinpointed out and further studied which resulted in many alternatives; finally a decision-making framework has been developed to prioritize all the renewal and modification projects.

However, the case study comes across a lot of difficulties and lessons are learned. A review of the case study results in an improved Value Methodology approach (section 3.7), following which maintenance improvements can be identified by function analysis and a value system can be developed to guide the decision-making process. The objective of this master thesis has been achieved.

A successful implementation of the improved VM approach yet requires several conditions which include team cooperation, available information and "stick to facts" attitude. Only when these criteria are achieved can a good and effective value study be carried out within Rijkswaterstaat. This research also looks into how to collect the necessary information (section 3.7) and how Rijkswaterstaat and contractors should cooperate (section 4.2).

The case study shows a lot of benefits from application of VM which include: constructive way of identifying improvements during preservation phase of an infrastructure assets; adequate decision-making framework for evaluation of maintenance investment alternatives; communication platform for Rijkswaterstaat and the contractors; and pinpointing out the required information. As a result, if the improved approach and the success factors are followed, Value Methodology can be well implemented and will be useful for Rijkswaterstaat and future contractors in identifying and making decisions on maintenance improvements.

## 5.2 Recommendations

*Recommendations for Rijkswaterstaat*

- **Building up necessary databases.**

  The VM process in the research identifies a list of necessary information which is needed during maintenance (refer to Section 3.7). However, it is not possible to gather all the information at the moment within Rijkswaterstaat. Some information is missing such as maintenance history data, safety report, environment assessment report and investment projects data. The following databases are recommended to be built in order that judgments can be made based on robust data.

  - A mature national Maintenance Management System shared between regions of Rijkswaterstaat;
  - Safety Report including Risk Manual, and Environment Assessment Report for each infrastructure asset;
  - Report representing Voice of the Customers through periodic surveys and user panel;
  - A database showing the cost of renewal and modification projects and the life span, to enable Life Cycle Cost Analysis.

- **Encourage "stick to facts" attitude.**

  Technical people in Rijkswaterstaat are very knowledgeable and experienced with infrastructure assets; however, they keep the knowledge in their heads. Although experience is rather important,

an adequate decision on investment projects should base on supported facts. People within Rijkswaterstaat trust each other's experience so much that little challenge is given on gut feeling. It is recommended to ensure the decision-making process auditable and evaluate how well that information supports the proposed projects. "Stick to the facts" attitude should be encouraged.

*Recommendations for further studies*

- **Further VM studies with contractor involved.**

  The VM case study in this research is done within Rijkswaterstaat and only people from Rijkswaterstaat are involved. This is because the new kind of Service Provider Contractor was not awarded and contractors did not start any maintenance planning work when the case study was carried out. Although this research foresees opportunities for cooperation between Rijkswaterstaat and the contractor, further studies with the contractor involved are recommended.

- **Further VM studies through the whole life cycle of an infrastructure asset within Rijkswaterstaat.**

  Although this research focuses on the preservation phase of infrastructure assets, it is found that similar approach can also be applied at any starting phase of a project: clients' requirements are identified and speculated; critical functions that support the requirements can be chosen based on a tradeoff between cost and performance. As shown in Figure 1 in the first chapter, VM can be applied through the whole life cycle of a project. It is extremely helpful at the moments that value improvements are in need (usually there is problem with cost, delivery time and quality).

  The Systems Engineering guideline for Rijkswaterstaat and ProRail introduces Value Methodology in the design process. It defines VM as a trade-off process which allows a choice to be made during detailed design. Although the definition is not fully correct, it addresses the usefulness of VM in design phase in Rijkswaterstaat.[39] In one of the countrywide service departments (bouwdienst (BWD) & DVS), Value Engineering is going to be applied in some pilots.

  Since so many applications are possible, it is worthwhile to look into a VM approach applying in the Systems Engineering context of an infrastructure asset and see how VM can help with asset management in Rijkswaterstaat. The interesting question is, at which points in the life cycle of an infrastructure system is VM worthwhile being applied in Rijkswaterstaat?

- **Studies on information model of infrastructure assets within Rijkswaterstaat.**

  Asset management, which Rijkswaterstaat is trying to apply, starts with asset inventory which Rijkswaterstaat currently does not have. They are going to build up the database with the help of contractor in the PIM pilot. Maintenance Management System is also being built. The problem is that, as this process takes a lot of time and money, Rijkswaterstaat should really think what should be included in the database, who is going to use it and how to use it properly? UK National Rail is trying to build up a database for all the railway stations with a software called ATRIUM, but unfortunately the work stopped halfway because they did not know well enough why they need such database and how detailed this database should go into[40].

  With the help of VM, this research pinpoints out information needed to identify renewal and modification projects. However, this is far from a full information model for an infrastructure asset. More studies with the objective to recognize necessary information for particular use are recommended.

- **Studies on better partnership between Rijkswaterstaat and contractors.**

  Customer oriented thinking is now starting to spread in Rijkswaterstaat. However, a good service level is not dependent on one party only. It is both Rijkswaterstaat and contractors to provide the service together. So how do we make the contractors have the same customer focus as Rijkswaterstaat? This research recommends VM as a communication platform. However, it requires sufficient cooperation and share of information between the two parties. To apply successful VM studies and also to provide good service to customers, research can be carried out in order to

[39] Reference: *Guideline Systems Engineering for Public Works and Water Management*, English version, ProRail and Rijkswaterstaat, May 2008.

[40] Source: Grontmij office in Wrexham, UK. A visit was paid there during this research.

define a better partnership between Rijkswaterstaat and contractors, for example, Public Private Partnership.

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## Abbreviations

DVM -- Dynamic Traffic Management Systems
EDC – Effective Date of Contract
EMC -- Electrical, Mechanical and Civil
EA -- Environmental Assessment
FMECA -- Failure Mode Effects and Criticality Analysis
FAST – Function Analysis System Technique
HVAC -- Heating, Ventilation, and Air Conditioning
IDA -- Institute for Defense Analysis
LED -- Light Emitting Diode
IEI -- Incremental Economic Indicator
INCOSE -- International Council on Systems Engineering
KPI – Key Performance Indicator
LCC -- Life Cycle Cost Analysis
MMS -- Maintenance Management System
MTBF -- Mean Time Between Failure
MTTR -- Mean Time To Repair
NHK -- Network Hansweert-Krammersluizen
PIM – Partnership Programme Infrastructure Management
PLC -- Programmable Logical Circuits
RAMSSHE -- Reliability, Availability, Maintainability, Safety, Security, Health and Environment
RCM -- Reliability Centered Maintenance
RE -- Reverse Engineering
RWS -- Rijkswaterstaat
SAVE -- Society of American Value Engineers
SCADA -- Supervisory Control And Data Acquisition
SPC -- Service Provider Contract
SE -- Systems Engineering
TO -- Brief Traffic Operation Directorate
TRIZ -- Theory of Inventive Problem Solving
IVM -- UK's Institute of Value Management
VE -- Value Engineer
VM – Value Methodology
WF -- Workshop Facilitator

# Appendix A – Best Case Practice of ProRail

*Project Information*

After increasing the rail capacity by one track, the existing underpass "De Koppeling", at Houten, the Netherlands, needed to get adapted to such changes. The underpass accommodates slow (pedestrians and cyclists) and fast road traffic (two lanes) which are crossing underneath the railway.

The current situation as shown in the figure A-1 below is that the underpass is crossed over by three bridges; a bridge for slow traffic (on the left), a bridge for rail traffic between Utrecht and Geldermalsen (at the centre), and a combined bridge for rail traffic between Houten and Houten Castellum and for slow traffic. The third bridge dates from 1999, and was built on a new land abutment (build outside the original construction).

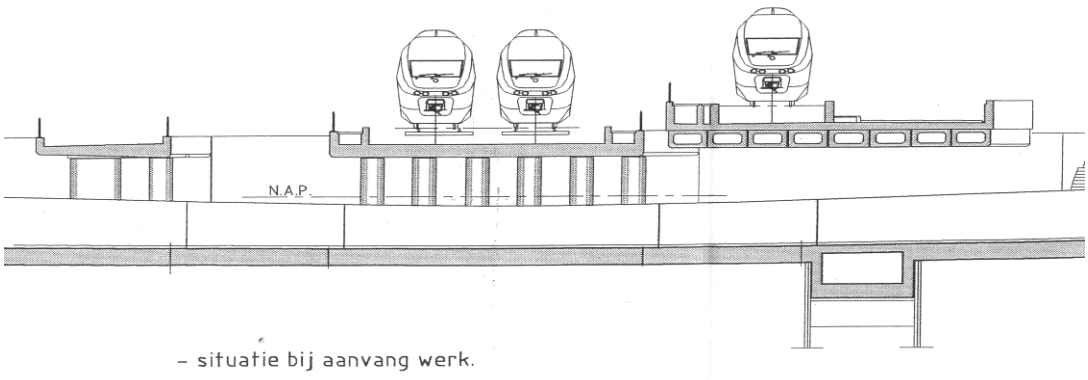


Figure A-1. A cross-section view of the underpass (current situation), (ProRail, 2006)

The original construction is balanced as the upthrust (due to groundwater) is damped by the weight of the construction (the left and centre bridge and the underpass itself). Pile foundations are not used. The concept could be thought of as a floating boat; therefore if the weight of the construction is reduced, the underpass will float.

*Value Management Study*

The goal was to optimize the project's value. The timing of the value management study was at the end of the preliminary design stage. The value management team consisted of the main project team members and the necessary discipline. An external specialist was involved to provide a critical and open view of the project.

The design proposed is shown in the figure below as;

- A new bridge will be built on the side, instead of the original rail bridge. The bridge will be the same as the bridge to the right in Figure A-2.
- The bridge to the right will be upgraded into two rail tracks;
- The two bridges for slow traffic will get renovated.
- Both rail bridges will be slid over the old bridge in the centre. This means that all the tracks must be raised over a relatively long distance.

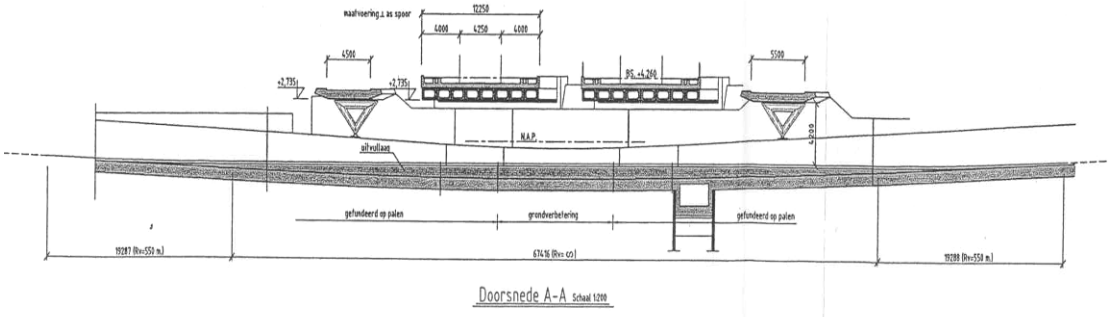


Figure A-2. A cross-section view of the proposed design, (ProRail, 2006)

During the presentation of the design and the discussion that followed, this information was added;

- Space needs to be reserved between the railways for a future platform (station).
- The outer tracks are for passing high speed trains. The inner tracks are for the slower stop trains
- The centre opening in the proposed design is not stated in the specification, and is thereby not a necessity. This is the same for all aesthetic features
- The track on the far right of the current situation is leading, due to high costs when changed
- The height in the underpass needs to be suited for special road vehicles and should be 4.20 meters.

| Criteria | Weight (0-1; sum W=1) |
|---|---|
| **1. Constructability**<br>Way of construction<br>Choice of materials | 0.30 |
| **2. Maintainability**<br>**a) rail related**<br>**b) non-rail related**<br>Choice of materials<br>Reaching areas to be maintained<br>Sensitivity to be maintained | <br>0.15<br>0.05 |
| **3. Fitness in future**<br>Flexibility for: expansion possibilities<br>Platform<br>Speed (rail)<br>Weight (rail) | 0.13 |
| **4. Availability**<br>a) rail<br>b) road | <br>0.22<br>0.05 |
| **5. Aesthetics** | 0.1 |

Table A-1. Performance Attributes (ProRail, 2006)

*Function Analysis*

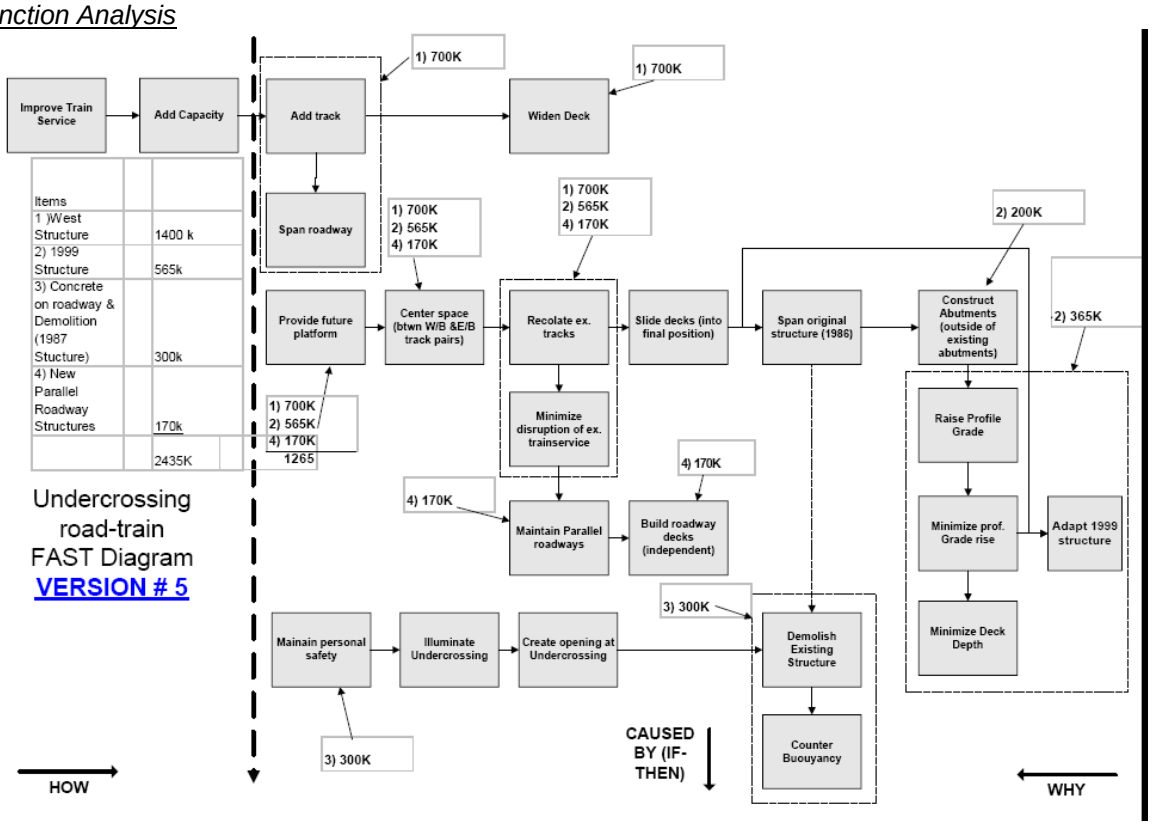


Figure A-3. Function Analysis of Best Case Practice of ProRail

Through the function analysis session, functions were selected to brainstorm ideas. After a diverging and converging process, four alternatives were evaluated;

| | Construction Cost [K] (x 1,000 Euros) | Cost Savings (x 1,000 Euros) | Potential Percentage Cost Savings | Performance (0 to 100) |
|---|---|---|---|---|
| **Baseline design** | 2,810.30 | | | 61.4 |
| **Alternative 1** | 1,243.30 | 1,567 | 56% | 69.2 |
| **Alternative 2** | 2,144.60 | 665 | 24% | 68.6 |
| **Alternative 3** | 739.9 | 2,070 | 74% | 72.8 |
| **Alternative 3a** | 682.6 | 2,128 | 76% | |

Table A-2, Evaluation of alternatives, (ProRail, 2006)

*Outputs*

At the end of the study, alternative 3a was chosen, and the design shown below was executed.

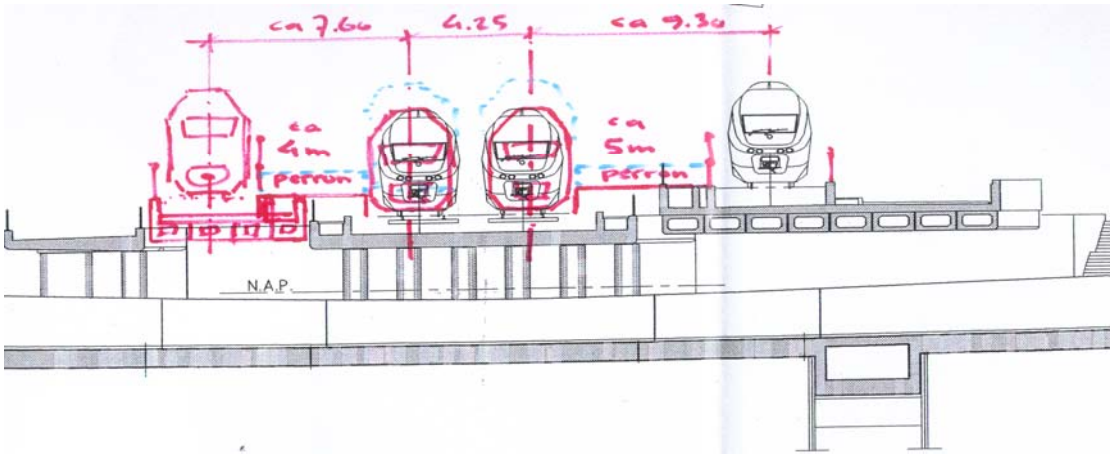


Figure A-4. Alternative 3a as final choice

*Benefits*

There will be no work on the railroad, which consequently means that there will be no or little disturbance for rail traffic, which is very important for ProRail. The alternative chosen is safer and has less procedures; no useless planning, and is much more cost effective. At the same time, the construction time is shorter; compensation for extra design effort.

# Appendix B – Interview Minutes in Case Study

## 1. Harry Karelse - Operator of Hansweert locks

**Time:** 13:30-15:00, 8th. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in 's Heerarendskerke

**Participants:**
- Harry Karelse: an experienced operator of Hansweert locks who works on site on daily base;
- Rob Heutinck: maintenance engineer from CMS Asset Management; Translator;
- Xiaowei Li: Value engineer.

**Content:**
As Harry Karelse did not participate in the first preparation meeting on 7th of April, general information of the project is introduced firstly to understand the problem. Value engineering and function analysis methodology is introduced as well. Afterwards, a list of questions are asked and answered when Rob Heutinck helps with the communication if there is language problem.

**Interview Minutes**: (H represents Harry and V represents Xiaowei)

V: Are the locks working 24 hours? What is your job during operation?

H: Yes, the locks work for 24 hours every day. We are divided into three groups and work in turn: 6:00-14:00, 14:00-22:00 and 22:00-6:00. Our job is to guide the ships to the right lock, open and close the doors, and make ships pass. We have radar system, calling system, operation system. We follow a list of steps by pushing the right buttons.

V: What kind and how many of ships are passing by?

H: An average of 45,000 ships pass by the lock every year. 10,000 of them are recreation ships, while others are cargo ships. During May to September, we have much more recreation ships.

V: How much time does it take to pass the locks? Is there any complaint from the customers?

H: That depends on the water level difference. With a difference of maximum 1.6m and minimum 0, the time varies from one hour to half an hour. When it takes too much time because of failure, the customer will complain.

V: What happens when there is a problem with the lock? How to find it and solve it?

H: When there is a problem, the particular red lights or alarm will tell us. Then we call the contractor to fix the problem. He should come within one hour and fix it as soon as possible. In the old days, maintenance people lived on site but not any more nowadays.

V: Do failures happen often? What is the frequency?

H: It is difficult to say. It varies every week. Maybe two small problems in one week, but maybe 15 in the next week.

V: Which parts are most likely to fail?

H: Most failures are electrical, for example, relays and switches. Sometimes mechanics also fail, for instance, the gear box of one hole in a door has some problem this week. So only four holes are still working (normally we have five), which delays a bit passing time for ships. When some part fails, we still try to make the whole system work.

V: Is there any regular maintenance? Does it have influence on the operation?

H: Contractors also do preventive maintenance, which means replacement or renewal. But this kind of maintenance is done when the parts are not working. So it does not disturb the traffic. However, new parts usually bring more failure and the supplier should come and fix the problem

which takes more time.

V: Is there any other kind of failure which has impact on the operation?

H: I cannot see much. Maybe failure of the nearby bridge has some impact. When there is fierce flood and wind, the locks stop working.

V: The locks also works as a passage for people who living in the neighborhood. Does it work well?

H: The locks are only for walking people and cycles to pass by. During operation, there is no problem for them to pass. There is no complaint from neighborhood.

V: What attributes do you consider to be important to describe the performance of the locks?

H: From the operation view, I only pay attention to the availability. What I care is just questions whether the ships can pass by and how long it takes.

V: What about other issues like safety and aesthetics?

H: These issues should be considered during design phase in the past, but not a big issue during operation. My only concern is to let ships go no matter how it looks like.

V: I saw the radar system in your operation room during my last visit to the locks. Is it newly installed? How do you think about new technologies?

H: Yes, the radar system is newly installed to improve the guidance for ships. We got training on the new system. Technologies help with performance. We have no problem with the new knowledge, but I can foresee the problem of young people with old fashioned installations.

V: Can you see other problems during maintenance of the locks?

H: More and more maintenance work is done and will be done by contractors. I am much worried about the transfer of the right data, knowledge and information. More miscommunication would lead to more problems and delays.

## 2. Charles Mollet & Bram Baas - Civil Engineers of Hansweert locks

**Time:** 11:30-13:00, 10th. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in 's Heerarendskerke

**Participants:**

- Charles Mollet: an experienced civil engineer from RWS who is familiar with the decomposition and principles of Hansweert locks;
- Bram Baas: Inspector from RWS who is in charge of maintenance operation in civil constructions;
- Kees Steenepoorte: civil maintenance planner in RWS; Translator;
- Xiaowei Li: Value engineer.

**Content:**
A list of questions about the decomposition of the locks, the performance killers and important attributes are asked and answered when Kees helps with the communication if there is language problem.

**Interview Minutes**: (C represents Charles; B represents Bram; V represents Xiaowei)

V: What is your job on Hansweert locks?

C: I am an inspector in civil part of the locks, mainly including the doors and ship guiding system. I have two responsibilities. First, when collision happens at the lock, I am the person who should go to the site, estimate the cost of repairing the damage, and ask insurance of the ships to pay for it. For example, not long before, one of the doors was damaged, causing a hole which did not influence the performance however. My second task is to inspection work on civil parts. The main task is to arrange work for contractors.

B: I am the inspector and in charge of maintenance operation in civil constructions. Contractors come for money. Sometimes they ignore some place of maintenance and I am the eyes and ears in the field.

V: What work is outsourced to contractors?

C: 15 years ago, all the maintenance work was done by RWS itself. Nowadays we outsource all the maintenance and even inspections to contractors, but we give orders. We control the process by contract with precise specifications. We have different contracts for different parts, but they need to cooperate.

V: How often does damage happen on civil structure?

C: It depends. The average number is 10 per year. 2 of the damages cause ships to wait.

V: Which parts usually break down and need maintenance?

B: The critical parts are electrical and mechanical installations especially electrical parts. Civil parts break down when there is a collision.

V: What kind of preventive maintenance are taking place?

C: For civil structures, normally we repair only when there is damage. The replacement of doors every 10 or 12 years could be a kind of preventive maintenance. When we replace doors, we also do some preventive maintenance for other parts, for example, lubrication of mechanical parts.

B: Maintenance for civil structures is usually done once or twice every year which is not often.

V: What options do you think can help to reduce failure or increase success?

C: To reduce failure, we should protect civil structures and reduce collision. One personal suggestion is, building steel beams some distance in front of the doors, to prevent damage to the doors which cost much and sometimes influence the availability.

B: To increase success, I think preventive maintenance is very important.

V: What attributes do you consider to be important to describe the performance of the locks?

C: I think safety is the most important, not only safety of operation and maintenance, but also safety for ships and people. We do not want anybody injured or even died in our Sluice.

B: Another concern is the availability of course.

## 3. Kees Steenepoorte - Maintenance Planner of Hansweert locks

**Time:** 13:30-14:15, 10th. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in 's Heerarendskerke

**Participants:**
- Kees Steenepoorte: maintenance planner in RWS especially for civil parts of the locks;
- Xiaowei Li: Value engineer.

**Content:**
A list of questions are asked and answered, about how to make plans, the price of the maintenance, and possible improvement.

**Interview Minutes**: (K represents Kees; V represents Xiaowei)

V: What is your job on Hansweert locks?

K: I was one of the maintenance planners. I took charge of the civil part, combined it with mechanical and electrical plans.

V:: Where does the fund come from?

K: Money comes from the government and from tax payers. Administrators in RWS have cost estimation each year for maintenance of an area or network.

V: How to make maintenance plans? Do you have any requirement or budget?

K: Plans are made according to experience and knowledge. We also have examples from other parts of RWS, in other region of the Netherlands. We make plans, of course with much attention on money. The infra-provider in Middelburg makes decisions.

V: What is the cost of maintenance of civil structures? What is the cost driver?

K: Well, the maintenance for civil structures cost much. For example, lock door replacement costs about €600,000, but we only need to do it every 10 or 12 years. Painting and replacing ship guiding constructions cost about €2,500,000 for a life span of 25 years.

V: Do you have any suggestions on how to improve the maintenance?

K: My advice would be, doing maintenance together maybe in one week for a whole year. During the week, one of the locks can be closed. However, this needs to be informed to the ships in advance. So good communication between three parties are very important: ships, operators and maintenance contractors.

## 4. Ger Duerinck - Mechanical Engineer of Hansweert locks

**Time:** 15:30-16:15, 10th. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in 's Heerarendskerke

**Participants:**
- Ger Duerinck: Mechanical inspector from RWS who is in charge of maintenance operation in mechanical installations;
- Dennis Vlassenrood: Consultant from Grontmij who works for PIM project in RWS; Translator;
- Xiaowei Li: Value engineer.

**Content:**
A list of questions about the mechanical part of the locks, the performance killers and important attributes are asked and answered when Dennis helps with the communication if there is language problem.

**Interview Minutes**: (G represents Ger; V represents Xiaowei)

V: What is your job on Hansweert locks?

G: I am the inspector and in charge of maintenance operation in mechanical installations. I instruct contractors about their activities and supervise their work.

V: Which parts usually break down? Do they have influence on the performance of the locks? What do you think is the performance killer?

G: One part that usually break down are the valves on doors to equal the water level on both sides. We have 25 such drivers, 5 for each of the doors and 5 spare ones. Average one failure happens on every valve each year. The main reason comes from the engine. As rising of water level, those engines have more time in the water which causes some failure because the engines are not so water-resistant. Another reason is friction of the mechanical parts. When there is only one or two valves break down, other valves can still carry out the performance but the speed of passing by will become lower. It takes one day to fix the problem, which causes effectiveness decrease. If there are more engines which break down together, there will be huge problem. I think it is a big

risk in the future.

The biggest problem for mechanical installations is that, they have only 5 to 8 years life cycle while civil parts have 10 to 15 years life span. To maintain some mechanical parts under or in the doors, the doors should be pulled out. However, this would be done in about 12 years. So different life spans lead to some problem.

V: According to the problem you mentioned, what options do you think can help to reduce failure or increase success?

G: For the engine problem, we can try to remove them out of water, to make them higher. Or we can import hydraulic engines which are water resistant. To solve problem of different life cycle, what we can only do is to install better mechanical parts or research on how to expand life spans, which needs money.

V: Do you do any preventive maintenance?

G: For mechanical installations, preventive maintenance is important such as lubrication. We have three months inspection which is carried out by contractors. And we also make detailed technical plans yearly.

V: What attributes do you consider to be important to describe the performance of the locks?

G: The most important function is to let ships pass by. So availability is the most important function. And the locks also work as flood protection, so safety is also one of the important attributes.

## 5. Jan Bosland - Advisor for Infra-Provider of RWS Zeeland

**Time:** 13:00-14:15, 11th. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in Middelburg

**Participants:**
- Jan Bosland: Advisor for infra-provider of RWS Zeeland (represents infra-provider);
- Xiaowei Li: Value engineer.

**Content:**
A list of questions about maintenance decision making tools, the performance killers and important attributes are asked and answered.

**Interview Minutes**: (J represents Jan; V represents Xiaowei)

V: What is your job in the organization and on Hansweert locks?

J: I am one of the advisors for infra-provider of RWS Zeeland (DZL). The infra-provider is a technical consultant of the director of DZL and there are another two consultants: traffic manager and water manager. These three managers help the director to make good decisions. And I can represent the infra-provider. We advice what should be done and which proposals are cost effective. So we suggest how to put money on different locks or bridges and we look at the whole network. Hansweert locks are part of the network.

V: Do you set a budget every year or for life-cycle?

J: We get a certain amount of money from government every year. Thus we have a budget on average locks every year. We consider the life-cycle cost and divide money to all the locks within the region. During past several years, we got less and less money from government. As a result, our maintenance level/ quality became lower and lower. Now the government realizes the problem and invests more to catch up the Basic Maintenance Level.

V: Are you cost or quality oriented when making plans?

J: We should be quality oriented but we have a budget. Now we become more quality oriented and

we expect innovations from contractors. In the future, it is the contractor to make plans and we finalize the plans by discussion. We should have some tools to communicate with them and evaluate the plans, for example, KPIs and PIs.

V: When technical people come up with an idea, what can they do?

J: They can write proposals. We look into the problem, to see where the critical failure lies with help of failure tree or Reliability Centered Maintenance, and we also judge whether the proposal is cost efficient. Then we can suggest the director what should be done or what must be done.

J: One problem is, people from different disciplines only look into their own business. They should look into problems on a higher level, cooperate with each other and make decisions by discussion. It is necessary to think in network way.

V: What attributes do you consider to be important to describe the performance of the locks?

J: I think RAMSHE is on the right track. Reliability, availability, maintainability, and environment are the issues we should consider. For Hansweert locks, important attributes are reliability and availability.

## 6. Jemmy Westveer - Electrical Engineer of Hansweert locks

**Time:** 12:30-14:00, 17th. April. 2008

**Location:** Rijkswaterstaat building in 's Heerarendskerke

**Participants:**
- Jemmy Westveer: an experienced electrical engineer from RWS who is familiar with the electrical installations of Hansweert locks;
- Xiaowei Li: Value engineer.

**Content:**
A list of questions about the electrical part of the locks, the performance killers and important attributes are asked and answered.

**Interview Minutes**: (J represents Jemmy; V represents Xiaowei)

V: What is your job on Hansweert locks?

J: I am the inspector and in charge of maintenance operation in electrical installations. I work as the technical supervisor, supervising contractors about their activities and work. Besides, I make 5 or 10 years work plan for maintenance of electrical installations while I also need to make daily work plans.

V: What kind of maintenance is there in electrical part and how do you plan that?

J: There are two kinds of maintenance. First is corrective maintenance. When operator or inspector finds a problem, they tell contractors to fix it. The second kind is preventive maintenance. We tell the contractor to do the inspection. The contractor suggests plans. After discussion, we take actions.

V: What kind of preventive maintenance are taking place? Why are they needed?

J: Every electrical installation had its own life span. Performance decreases quickly after several years. We should renew it at the critical time to prevent it from breaking down suddenly. Besides, if some products are not produced or there are no spare ones any more, we should replace them with new products. Otherwise, it is not safe if it does not perform any more. We do preventive maintenance to keep the value of installations.

V: Which parts usually break down and need maintenance?

J: Relays, switches break down most often but maintain most easily. Computer system, gear box

and the speed control system break down not so often, but difficult to maintain. The most important electrical parts are energy supply and central computer which controls the whole process. Thus we have back-up system in case they break down.

V: What options do you think can help to reduce failure or increase success?

J: In my opinion, high techniques and advanced knowledge is very important in the future, not only for the contractor, but also for RWS itself. Furthermore, careful inspections can also help to reduce failure.

V: What attributes do you consider to be important to describe the performance of the locks?

J: Reliability especially for the electrical parts is very important. You cannot trust a system which breaks down too often although every breaking down period is very short. Availability is of course the most important criteria for a lock. For the contractor, the problem should be responded and fixed in time.

## 7. Henk Aarnoutese - Mechanical Engineer of Hansweert locks

**Time:** 9:30-10:00, 21st. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in 's Heerarendskerke

**Participants:**
- Henk Aarnoutese: an experienced mechanical engineer from RWS and also one of the project leaders who is familiar with the mechanical installations of Hansweert locks;
- Kees Steenepoorte: civil maintenance planner in RWS; Translator;
- Xiaowei Li: Value engineer.

**Content:**
A list of questions about the mechanical part of the locks, the performance killers and important attributes are asked and answered when Kees helps with the communication if there is language problem.

**Interview Minutes**: (H represents Henk; V represents Xiaowei)

V: What is your job on Hansweert locks?

H: I am an expertise advisor in mechanical part of Hansweert Locks. As one of the project leaders, I am involved in the maintenance planning and supervision of contractors' activities.

V: What kind of maintenance is there in mechanical part?

H: In mechanical installations of the locks, what we do mostly is preventive maintenance. For example, replacing mechanical parts under the door costs a lot of money and effort. We have a test on our Emergency Power Supply every two months, in case the power shuts down once every year on average. Besides, we also do corrective maintenance when some parts break down.

V: Which parts usually break down and need maintenance?

H: The pole/beam for walking people usually breaks down. Valves in the door also break down very often because of fatigue and friction. The steel cable does not correctly work sometimes which mainly comes from problems of the tension and speed control.

V: What are the cost drivers?

H: The preventive maintenance of moving system under door cost most. Besides, maintenance on valves also costs much.

V: What options do you think can help to reduce failure or increase success?

H: The old fashioned valves can be replaced with hydraulic system at the right time by considering life span. Every time we think about solutions, we should focus on long term run.

V: What attributes do you consider to be important to describe the performance of the locks?

H: Availability, safety and maintainability are considered important for me. Problems should be fixed within required time.

## 8. Wies de Blok - Electrical Engineer of Hansweert locks

**Time:** 10:00-10:30, 21st. April. 2008

**Location:** Meeting room of Rijkswaterstaat building in 's Heerarendskerke

**Participants:**
- Wies de Blok: an experienced electrical engineer from RWS and also one of the project leaders who is familiar with the electrical installations of Hansweert locks;
- Kees Steenepoorte: civil maintenance planner in RWS; Translator;
- Xiaowei Li: Value engineer.

**Content:**
A list of questions about the electrical part of the locks, the performance killers and important attributes are asked and answered when Kees helps with the communication if there is language problem.

**Interview Minutes**: (W represents Wies; V represents Xiaowei)

V: What is your job on Hansweert locks?

W: I am an expertise advisor in electrical part of Hansweert Locks. As one of the project leaders, I am involved in the maintenance planning and supervision of electrical contracts.

V: As the most complicated and important parts, what are included in electrical installations?

W: Power supply; fire equipment for safety; communication service; speed regulation system; detect system for the door; level measuring system and relay system. Those systems are included in electrical contracts.

V: Which parts usually break down and need maintenance?

W: Relay system break down most often. Different parts are controlled by different relays. When there is problem, we need to find the right control relays by asking operators about the alarm light and numbers. About every four or five months, there is a real failure that the locks stop working. The contractor comes, and fixes the problem within one or two hours.

About every five years, there is a failure of power supply because of a fire of main supply units or melting of them. Then we use emergency supply, which is backup motor or engine.

Besides, valves in the door, poles and water-level measuring system are the parts that frequently break down. There are 25,000 electrical connections which may cause failure.

V: What are the cost drivers?

W: We have €750,000 budget every year for electrical parts. A relay only costs €25 while a motor or traction engine costs €25,000.

V: What options do you think can help to reduce failure or increase success?

W: New techniques can help, for example, a PLC system instead of relays. Inspections of those thousands of connections are important, as well as preventive maintenance. In my opinion, reduction of failure is more important than cost. Furthermore, we should provide good information for operator.

V: What attributes do you consider to be important to describe the performance of the locks?

W: First, the reliability should be at least 99.99%. Second, safety is important including the traffic signal and security. Last, availability for ships is also important.

For the contractors, both the reaction time and solving time should be limited within half an hour. Besides, right knowledge and experience is rather important.