SafeLife-X *Safe Life Extension management of aged infrastructures networks and industrial plants*

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D6.1 Note describing the business cases and their components

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Utrecht, 31th August 2015

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1 Introduction

1.1 Purpose of this document

This document illustrates the economic feasibility of solutions to extend the technical and functional life of infrastructure. Case studies have been conducted for the following asset categories:

- Wind
- Hydraulic structures
- Bridges
- Power
- Industry
- Process plant (storage)

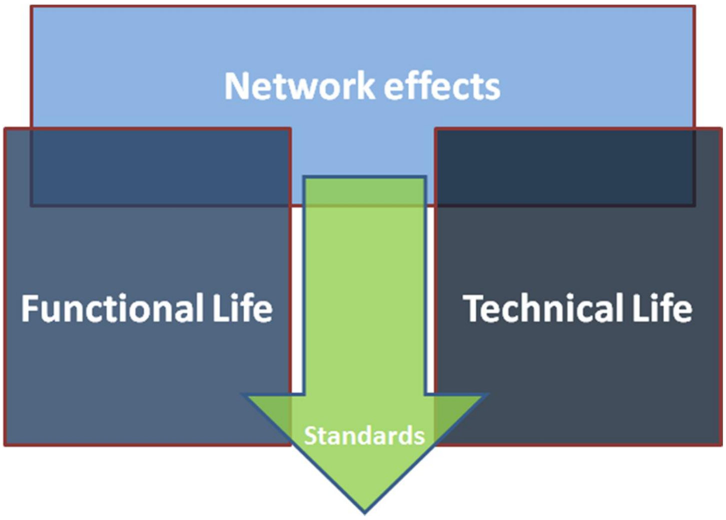
From these, four case studies were selected to illustrate the economic rationale (i.e., the 'business case') for life extension:

- Bridges
- Hydraulic structures
- Wind turbines
- Process plants

1.2 Rationale for analysis

The overall rationale for the analysis is summarized in Figure 1 below. Functional life and technical life are defined by Standards for infrastructure, plants and other built assets. At the meta-level, the Technical (condition) and Functional (performance) life of assets are simultaneously conditioned by network effects, for example the larger number of sluices and weirs in a complex water infrastructure.

Figure 1 Methodology for case study analysis.

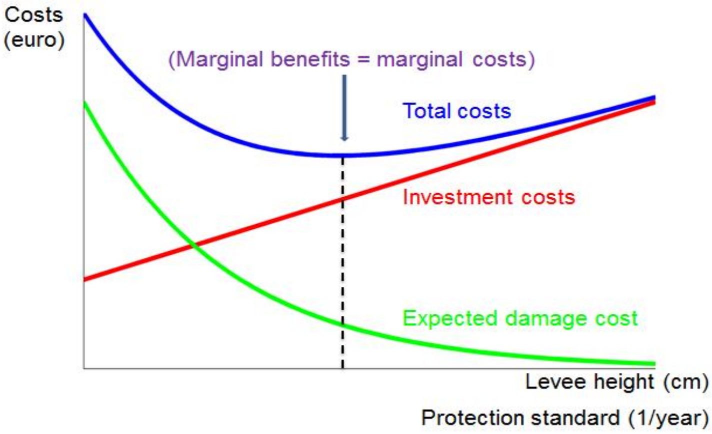


The overall analysis was conducted in four steps: 1) technical assessment; 2) performance assessment; 3) evaluation of intervention strategies; and 4) economic analysis (business case, life cycle costing).

The economic challenge is to align Functional Life with Technical Life, both at the level of the object and at the network level. The quest is for an economic optimum between intervention for replacement and/or rehabilitation on the one hand, and performance on the other. Figure 2 demonstrates the principle, using flood protection as an example. The optimisation principle is to minimise the combined costs associated with asset operation. These are the costs of life extension and the costs of expected (residual) disruptions in service and/or function. Investments are made until the cost of the last investment (i.e. the marginal cost) no longer outweighs the further improvements in safety of the asset (i.e., the marginal benefits). At this point – where marginal costs equal marginal benefits – the total costs are minimal, and the extended life of the asset is safe and economically optimal. Both higher and lower levels of safety than the economically optimal one lead to higher total economic costs.

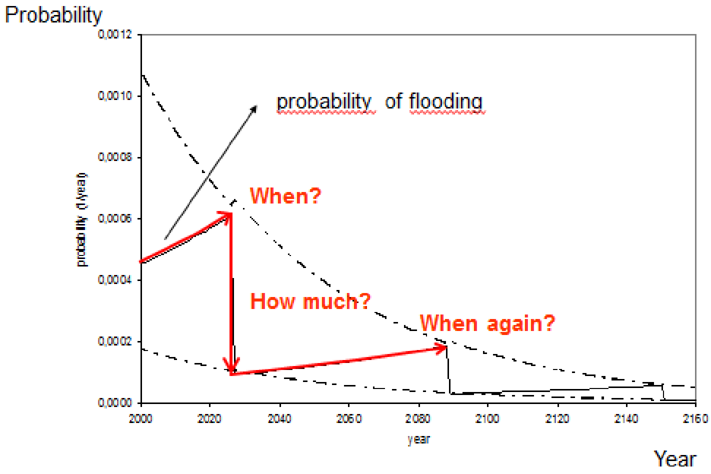
The economic analysis can be made more realistic by means of dynamic optimisation, allowing such factors as economic growth, climate change and changing demands for infrastructure services to be taken into account (Figure 3). This enables the analyst to address the 'when', 'how much' and 'when again' questions associated with rehabilitation and replacement for safe life extension.

Figure 2 Rationale for economic analysis.



Efficient Flood Standards, SoC14, JM Kind

Figure 3 Dynamic optimization of costs and benefits.



The business cases have been developed based on the interventions identified as best practice in WP2 and are considered to be applied throughout the cases as described in D3.1. As such, the interventions have not been the explicit focus of the analysis within the business cases.

2 Business Case: Bridges and other structures of transport infrastructure

2.1 Background

Bridge assessment and maintenance planning requires two key inputs. First, a comprehensive set of aging functions is required for all relevant types of bridges and structures. These aging functions will need to distinguish between the most commonly used materials, i.e. concrete, steel and composites. Second, rules are required to guide the implementation of a composite condition index for structures for subsequent use in risk-based management concepts.

A key feature of bridge asset and maintenance planning is that the planning and design of a program of monitoring and testing for aging is relatively straightforward: it can be conducted by one or more qualified senior engineers, provided that they have access to adequate support and resources. In process and power plants, for example (see Chapter 5) a team of specialists is required to design and manage a proper test program. Another distinguishing factor is that corrosion damage is not as significant for bridges as it is for other asset categories. Hence, life cycle costs give an adequate approximation of aging and thus models can be built mainly on this aging factor.

2.2 The business case

From an economic perspective the analytical task is to cost-effectively align a bridge's functional life (FL) with its technical life (TL), both at the level of the individual asset (object) and at the network level, and taking into account social barriers. The analysis thus captures four dimensions: technical life; functional life; network effects; and stakeholders. The network level is currently not considered. The stakeholder dimension is reflected through the broader costs associated with loss of performance: for example, disruption of traffic due to bridge closure for maintenance.

When FL (or TL) are coming to an end, two strategies are available: replacement or rehabilitation of the bridge. The case for a safe extension of a bridge's life amounts to an articulation of the economic optimum between the costs of the intervention (rehabilitation or replacement to safeguard functional or technical life) on the one hand and the costs ('penalty') of loss of performance (e.g. due to limited availability or increased risk of failure) on the other.

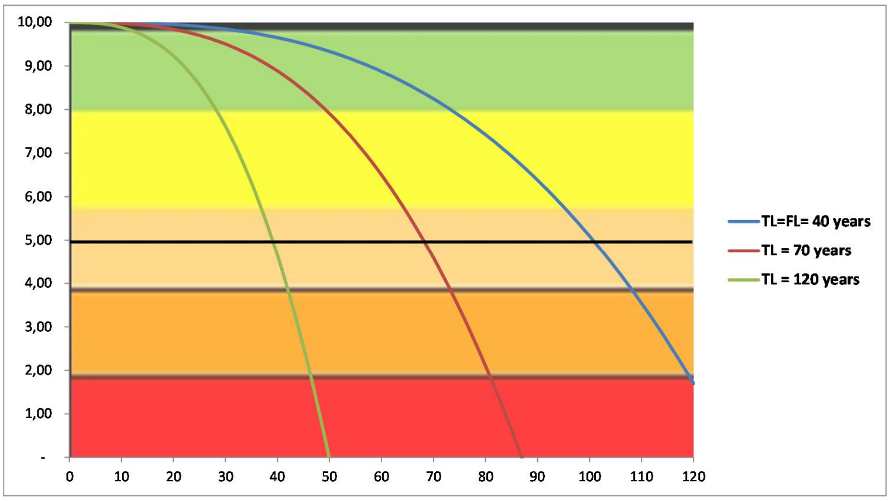
The analysis for bridges is based on a unified case, i.e. a generic four-lane bridge. The costs of replacing such a bridge are € 6 million; rehabilitation costs are € 2.4 million (set as a maximum of 40 % of the costs of replacement) and standard annual operating and maintenance (O&M) costs are € 52,000.

The benchmark technical life of a bridge at construction was 40 years. However, empirical evidence suggests that the technical life of bridges can typically be extended to 70 - 120 years. Whether functional life extension to match the extended technical life makes economic sense depends on how the trade-off between rehabilitation and replacement is framed. Rehabilitation extends the functional life of a bridge; however, original design capacity should still be well within required functionality, while rehabilitation works also negatively affect performance, for example the availability of a bridge for its regular traffic during implementation of the works. Replacement, on the other hand, is typically much more expensive, and possibly even more disruptive to traffic.

2.2.1 Performance functions

In generic terms a longer technical life means that more effort has to be made to keep the bridge's functional life at par, with commensurate effects on performance (more rehabilitation interventions, more frequent reductions of bridge availability. Figure 4 illustrates this principle for three technical life spans (40, 70 and 120 years).

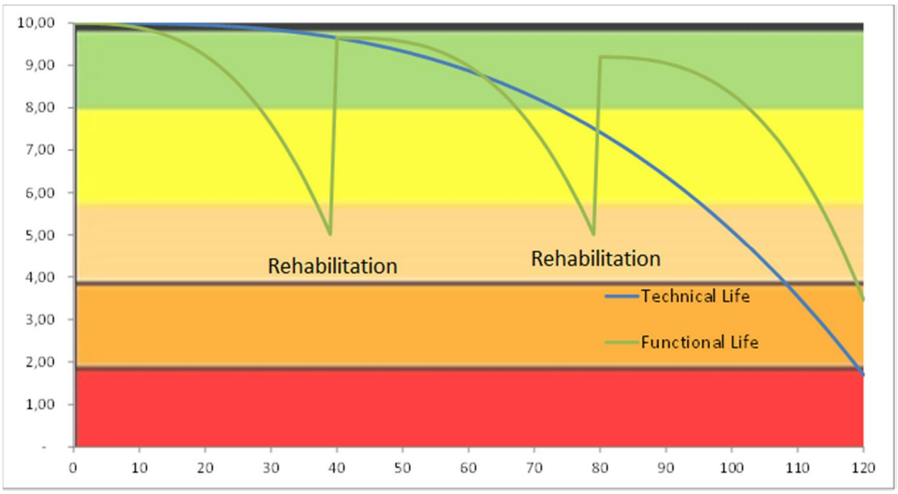
Figure 4: Technical life and performance.



2.2.2 Maintenance functions

The principle of performance degradation over time with rehabilitation interventions during which the performance can be brought back up to the required standard is shown in Figure 5. The number of interventions is critical here, as this parameter determines both the life extension (FL > TL) and the costs of unavailability of the bridge.

Figure 5 Maintenance interventions.



2.2.3 Availability

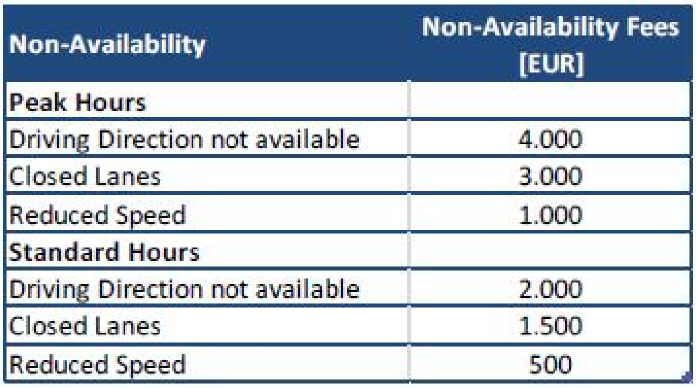
For the purpose of this business case *availability* is used as a proxy of performance, allowing full comparability between cases. The value of time, for example the cost of extra commuting time spent during bridge closure, may be a more accurate measure; however with this measure benefits and costs would accrue to different economic entities, making comparisons difficult.

The basic principle is that non-availability of the bridge implies a cost in euros. This non-availability cost is calculated as:

Duration of intervention [hours] x fee [euro/hour] x availability section weighting;

The non-availability cost is effectively a penalty. An example of non-availability fees is provided in Table 1 below. Based on these unit figures the non-availability costs due to rehabilitation requiring all lanes to be closed for four months would be € 648,000. Non-availability costs due to replacement which renders one driving direction unavailable for 18 months would be € 3.9 million.

Table 1 Non-availability fees[1].



Non-Availability	Non-Availability Fees [EUR]
Peak Hours	
Driving Direction not available	4.000
Closed Lanes	3.000
Reduced Speed	1.000
Standard Hours	
Driving Direction not available	2.000
Closed Lanes	1.500
Reduced Speed	500

Figure 6 illustrates the combined impacts for various bridge closure options on the availability of the bridge for use by road traffic. Options include partial and full closure, closure at particular times of day; and speed reductions. The combined effects over time translate to an availability level.

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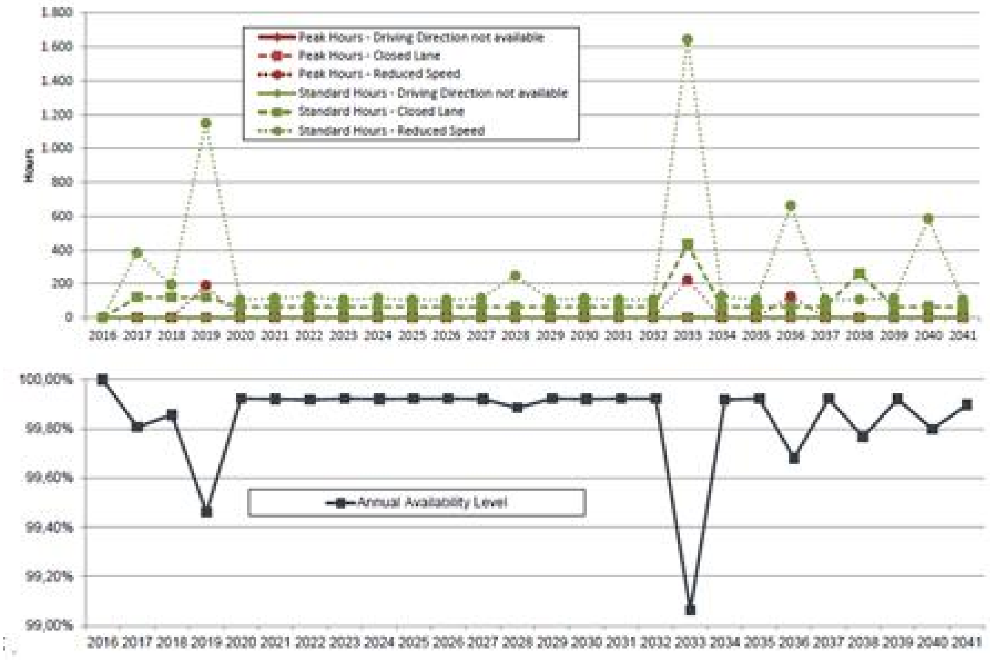
[1] From: Veit-Egerer, R., Life Cycle Engineering & langfristige Erhaltungsplanung von Ingenieurbauwerken in der Praxis, 2014

Figure 6 Availability.



2.3 Analysis

Analysis of the business case is structured as follows. Three economic indicators - cash flow, life cycle costs and capital & operating expenses – are used to characterise three alternative scenarios for three cases: a base case, the 'availability' case and the 'changed perspective' case. The base case represents replacement of a unified bridge after 40 and after 80 years. Two replacement scenarios represent technical lives of 70 and 120 years, respectively. The timing of replacement and rehabilitation interventions for these two scenarios are shown in Table 2 below.

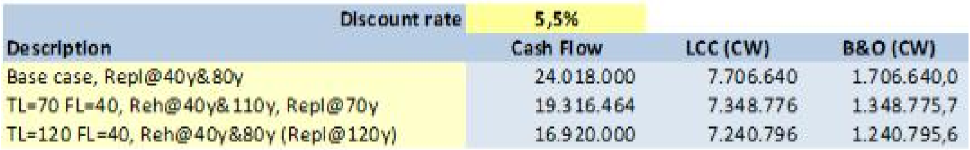
The changed perspective alternative case is represented by considering all expenditures before year 70 as sunk-costs and consequently planning interventions for the following 40 years. The

Table 2 indicates that delayed replacement and rehabilitation significantly reduce cash flows, life cycle costs and O&M costs.

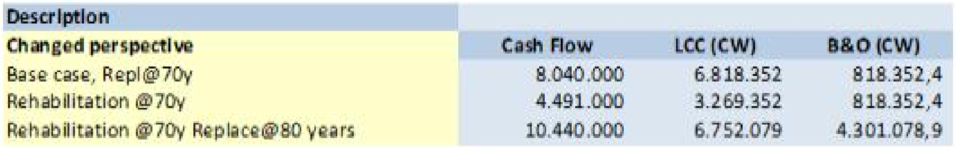
When availability is considered, as a penalty for the bridge being unavailable during replacement or rehabilitation, in the case over the full livetime the effects on cash flow and costs appear less significant than for the changing perspective case (Table 3).

Table 4 compares the 'change perspective' case with the 'changed perspective PLUS availability' case', indicating the relative effects of availability on cash flow and costs.

Table 2 Base case vs ' changing perspective' case.

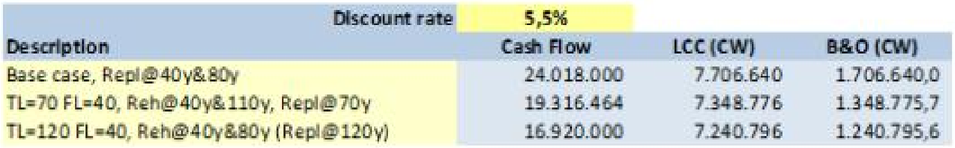


Discount rate	5,5%		
Description	**Cash Flow**	**LCC (CW)**	**B&O (CW)**
Base case, Repl@40y&80y	24.018.000	7.706.640	1.706.640,0
TL=70 FL=40, Reh@40y&110y, Repl@70y	19.316.464	7.348.776	1.348.775,7
TL=120 FL=40, Reh@40y&80y (Repl@120y)	16.920.000	7.240.796	1.240.795,6

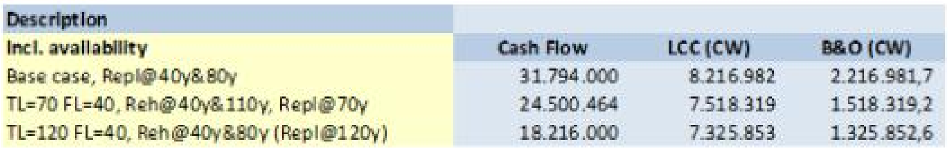


Description			
Changed perspective	**Cash Flow**	**LCC (CW)**	**B&O (CW)**
Base case, Repl@70y	8.040.000	6.818.352	818.352,4
Rehabilitation @70y	4.491.000	3.269.352	818.352,4
Rehabilitation @70y Replace@80 years	10.440.000	6.752.079	4.301.078,9

Table 3 Base case vs case with availability factored in.

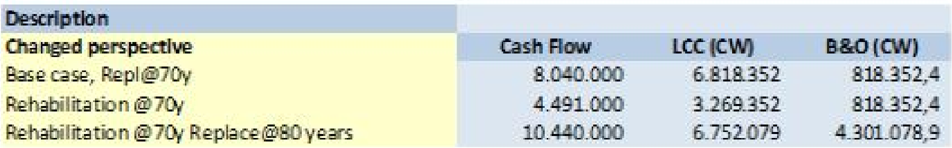


Discount rate	5,5%		
Description	**Cash Flow**	**LCC (CW)**	**B&O (CW)**
Base case, Repl@40y&80y	24.018.000	7.706.640	1.706.640,0
TL=70 FL=40, Reh@40y&110y, Repl@70y	19.316.464	7.348.776	1.348.775,7
TL=120 FL=40, Reh@40y&80y (Repl@120y)	16.920.000	7.240.796	1.240.795,6

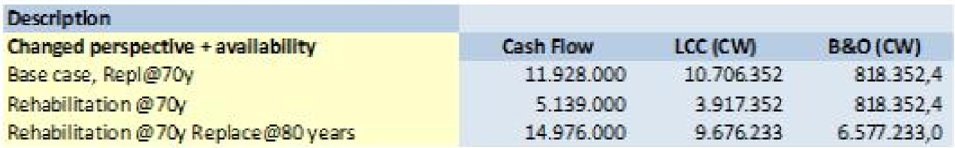


Description			
Incl. availability	**Cash Flow**	**LCC (CW)**	**B&O (CW)**
Base case, Repl@40y&80y	31.794.000	8.216.982	2.216.981,7
TL=70 FL=40, Reh@40y&110y, Repl@70y	24.500.464	7.518.319	1.518.319,2
TL=120 FL=40, Reh@40y&80y (Repl@120y)	18.216.000	7.325.853	1.325.852,6

Table 4 ' Change perspective' case vs ' changed perspective PLUS availability' case.



Description			
Changed perspective	**Cash Flow**	**LCC (CW)**	**B&O (CW)**
Base case, Repl@70y	8.040.000	6.818.352	818.352,4
Rehabilitation @70y	4.491.000	3.269.352	818.352,4
Rehabilitation @70y Replace@80 years	10.440.000	6.752.079	4.301.078,9



Description			
Changed perspective + availability	**Cash Flow**	**LCC (CW)**	**B&O (CW)**
Base case, Repl@70y	11.928.000	10.706.352	818.352,4
Rehabilitation @70y	5.139.000	3.917.352	818.352,4
Rehabilitation @70y Replace@80 years	14.976.000	9.676.233	6.577.233,0

When the O&M costs (in present value) over time for the two alternative cases are compared against the base case, it becomes clear that the changing perspective leads to the greatest O&M cost shift (Figure 7 Present value of O&M, including replacement and/or rehabilitation.

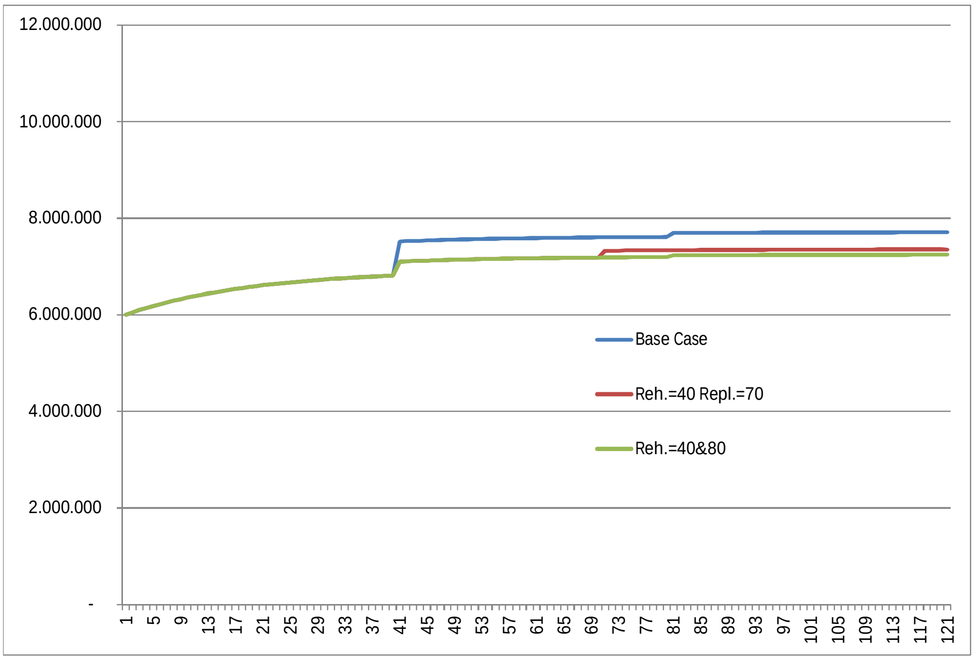


Figure 8 and Figure 9).

Figure 7 Present value of O&M, including replacement and/or rehabilitation.

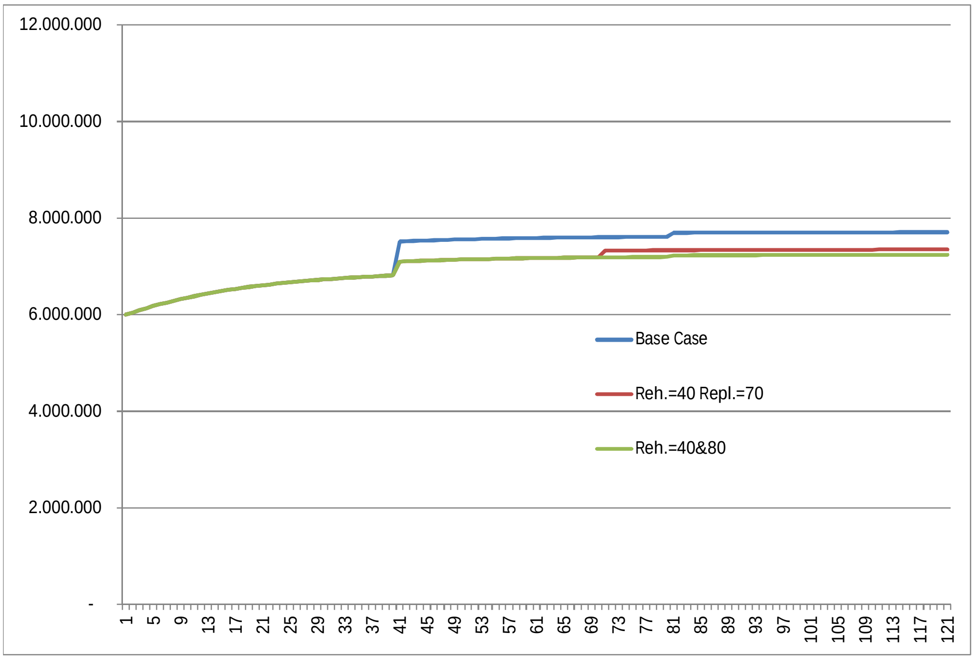


Figure 8 Present value of O&M, including replacement and/or rehabilitation (including availability).

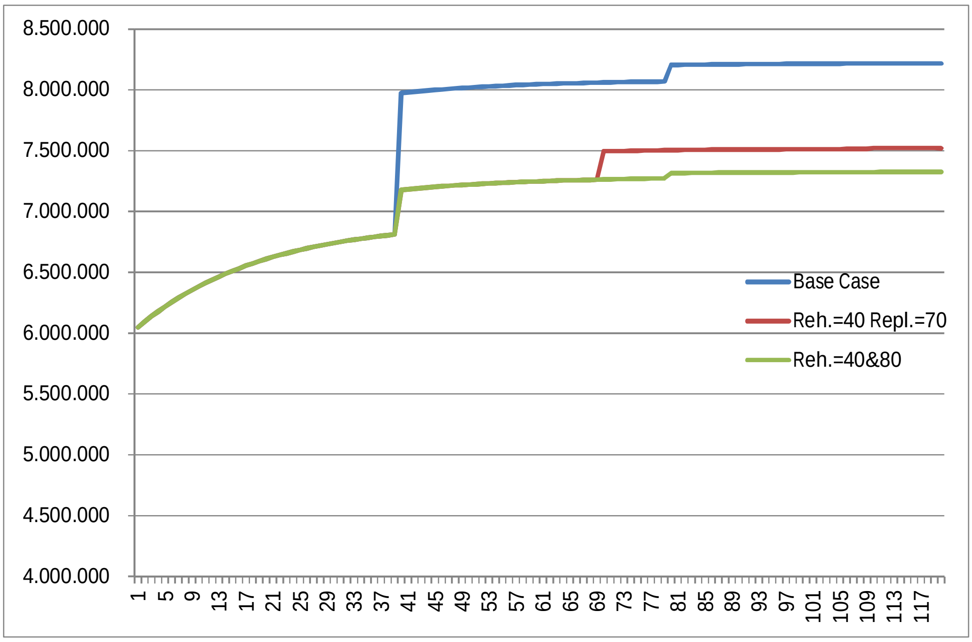
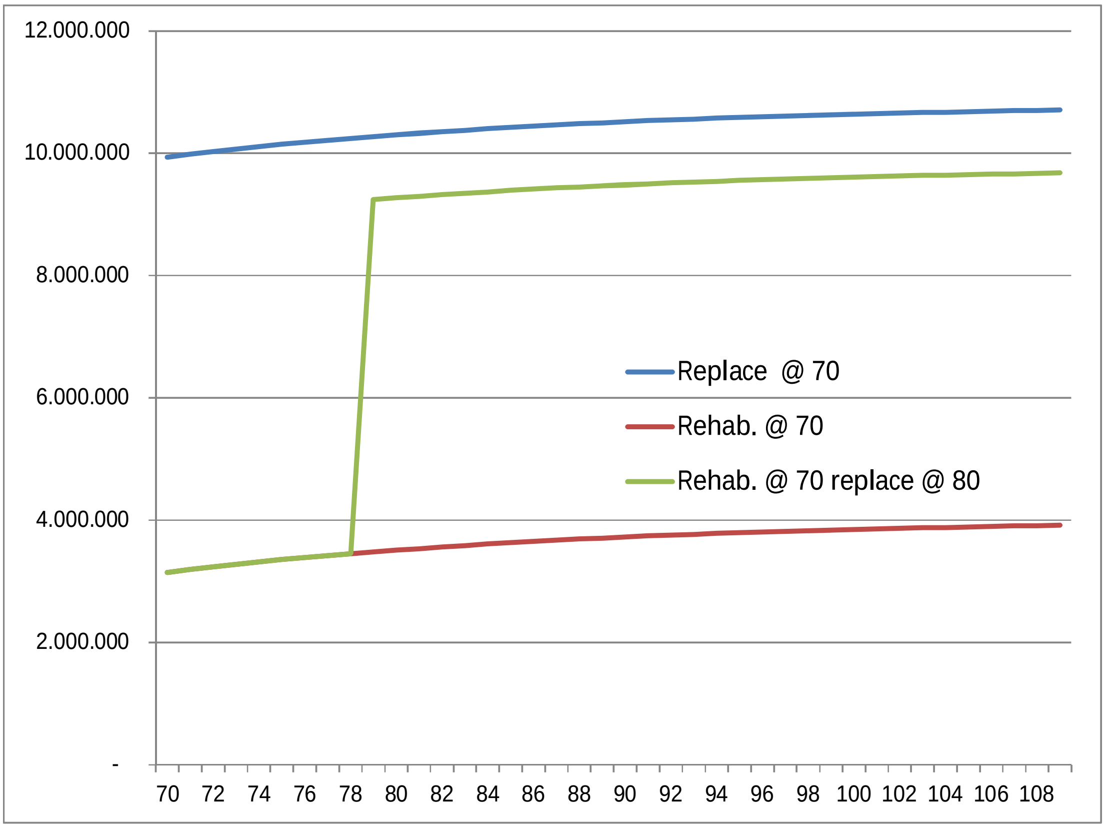


Figure 9 Present value of O&M, including replacement and/or rehabilitation (including changed perspective).



2.4 Conclusions

Knowledge on technical condition and remaining technical life (risks) is important. Furthermore, decisions should include evaluation of both actual and future performance, including network effects. Finally, relatively large budgets can be used for research/innovation and rehabilitation when replacement can be delayed

3 Business Case: Hydraulic Structures in the River Rhine

3.1 Background

The business case for hydraulic structures is exemplified by the replacement of the sluices and diversion structures in the northern branch of the river Rhine, the “Nederrijn”. During the 1960s three weirs were built in one of the river Rhine’s branches to control the distribution of water discharge over this branch and to enable shipping transport in times of low water discharge. In times of high water discharge the weirs are opened to release water downstream. Near the weirs sluices have been built to enable the vessels to pass the weirs.

The weirs are located in an area that is part of the Dutch flood management programme *Room for the River*. This programme aims to manage higher water levels through increased buffer capacities. Measures will be taken at more than 30 locations to allow the river Rhine to flood safely. The effects of this programme are incorporated in the business case.

The retrofitting, maintenance and replacement required to maintain the functionality of the hydraulic structure at Lobith reflects just one instance in a larger maintenance program covering some 650 hydraulic structure assets that the Dutch government is planning to carry out over the coming decades.

The business case addresses the economics of hydraulic structures asset management at two decision-making levels:

1) the level of individual physical asset(s) (i.e. objects such as weirs and sluices) and
2) the meta-level of flood risk.

The case of safe life extension of hydraulic structures has two major unique characteristics. First, unlike for other asset categories, external (hydraulic, environmental) conditions define the operating space of structures. Materials have to be designed and tested to operate under these (sometimes extreme) conditions. Second, it is important to address changing loading conditions of hydraulic structures. This is required to adequately reflect external, non-controllable factors.

3.2 The Business Case

3.2.1 Lobith sluices and weirs

The ageing infrastructure that is present in the complex of sluices and weirs in the Nederrijn invokes an economic trade-off between the costs of rehabilitation and/or replacement on the one hand, and the benefit of an extended functional life on the other. Some 250 hydrological structures in the Netherlands, out of a total of ~650 structures, are approaching the end of their technical life and require urgent replacement. The estimated cost is between 10 and 100 million per structure, i.e. a maximum total investment of 250 x € 100 million = € 25 billon. This reflects the total public investment that approaches the € 27 billon investment that the Dutch Government will be making under its Second Delta Programme. There is some overlap as the Delta Programme also covers the replacement of some hydrological structures; it is mainly focussed on dikes, however, and does not consider major hydrological structures such as the sluices and weirs near Lobith.

The uncertain aging aspects of this case are: the actual state and history of the structure; future development of the hydraulic load due to climate change and measures such as *Room for the River*; and future functional specifications due to changes in shipping (e.g. types and frequencies of vessels).

Currently the actual state of hydraulic structures in the Netherlands is characterised by means of assessment of the performance of a structure against its original design criteria. Actual system requirements are currently not a leading principle in rehabilitation/replacement decisions.

Economic assessment is undertaken based on replacement cost versus expected rehabilitation costs for life extension. The economic assessment is based on individual cost components as summarised in Table 5 below. The table illustrates that maximum rehabilitation costs are approximately 40 per cent of replacement costs, as only rehabilitation to the superstructure is feasible. Rehabilitation for technical life extension for the substructure (civil works) is normally not possible, thus limiting maximum rehabilitation costs to 40 per cent of replacement costs.

Table 5 Cost components of hydraulic structures – bridges and sluices.

Bridges (moveable)

Civil works	60%
Steel components	26%
Mechanical parts	12%
Electrical Inst.	2%

Sluices

Civil works	50%
Steel components	14%
Mechanical parts	6%
Electrical Inst.	5%
Other	25%

3.2.2 Flood Risk Assessment

Protection against flooding is a vital issue in the Netherlands since 55% of this country is susceptible to flood risk. Each year the Dutch government spends roughly € 1 billion on construction and rehabilitation of dikes and dunes. In total there are 3,500 km of primary dikes and dams in the Netherlands.

Flood risk management aims at optimal protection of society against the damaging impacts of flooding. The Dutch Government is moving towards an economically optimal (i.e., cost-efficient) level of protection, requiring investments totalling 27 billion (in 2013 euros) up to the year 2050.

In the context of the Dutch Delta Programme, economically efficient flood protection standards for the entire Netherlands have been calculated using combined cost-benefit analysis and flood risk assessment (Kind, 2014). With this approach economically efficient flood protection standards are no longer fixed depending on geographical location in the Netherlands, but now depend on the actual value at risk. As such, economically efficient flood protection measures can differ significantly from current flood protection standards.

3.3 Economic Analysis

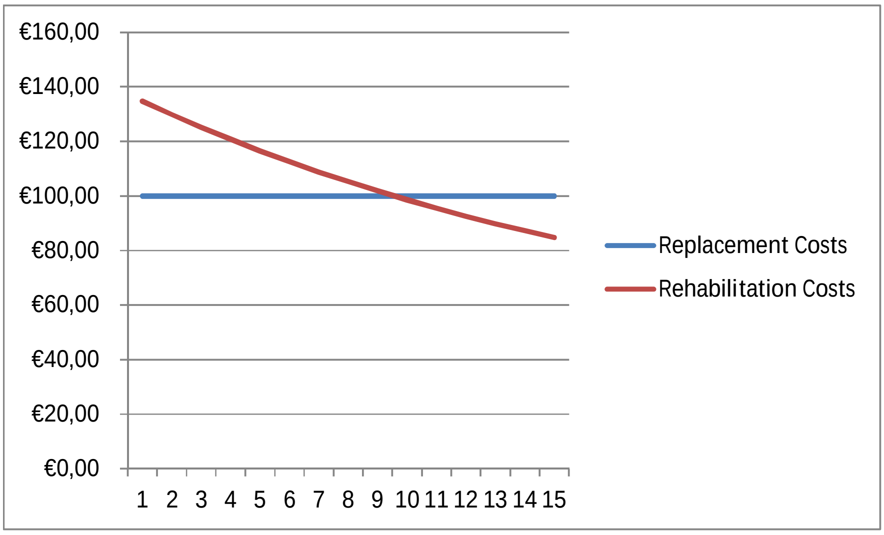
3.3.1 Hydraulic structures

For hydraulic structures such as sluices and weirs the trade-off between replacement and rehabilitation is summarised in Table 6 and Figure 10. Assuming a discount rate of 5.5% and rehabilitation costs set at a maximum of 40 per cent of replacement costs, the minimum extension of technical life that should be achieved in an economically efficient way is an average of 10 years. When rehabilitation costs are less than 40 per cent, the required extension of FL is commensurately less.

Table 6 Replacement cost vs rehabilitation cost for hydraulic structures.

Investment Costs	€ 100,00
Rehabilitation Costs	€ 40,00
Interest Rate	5,5%
Min. ext. of FL	10

Figure 10 Rehabilitation and replacement over time.



3.3.2 Flood risks

Cost-benefit analysis of flood risk measures (Kind, 2014) suggests that it is economically efficient to raise protection standards especially along the rivers Rhine and Meuse. For many dike ring areas[2] in the coastal region, existing legal flood protection standards can be considered too conservative. Additional Monte Carlo analysis shows that in light of many uncertainties, these conclusions were robust. Figure 10 below explains the principles of minimisation of the total cost of flood damage. For each flood risk management area an optimum exists where the marginal benefits equal the marginal costs of flood risk protection measures. This optimum is determined by a risk-weighted damage cost function (assuming linear investments).

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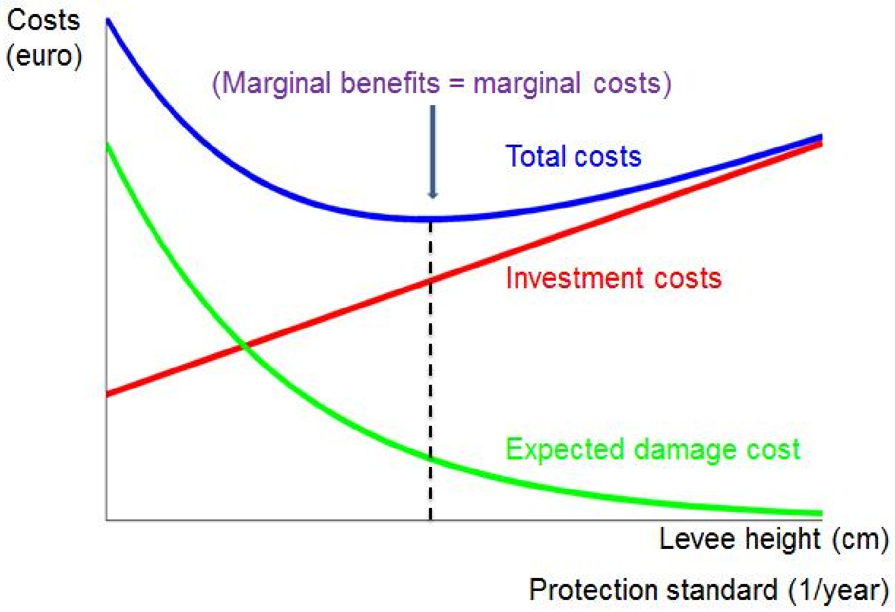
[2] An area protected against water by primary dikes and/or dunes as well as hydrological structures such as sluices or pumping stations.

Figure 11 Minimisation of the total cost of flood damage.



Efficient Flood Standards, SoC14, JM Kind

The risk-based cost-benefit analysis of flood protection does not support the general increase of the legal flood protection standards as recommended by the second Delta Committee in 2008[3]. The risk-based approach suggests that it is economically efficient to limit increased standards to *selected* critical regions. These findings, accepted as a basis for policy by the Dutch Minister of Infrastructure and Environment, led to an estimated investment cost saving of € 7.8 billion (2005 prices) while still strengthening the country's defense against flooding (Table 7).

Table 7 Total cost of flood protection compared against Business as Usual (BAU).

	Investment cost [€ billion]	Flood damage cost [€ billion]	Total cost [€ billion]
No change (BAU)	0	15	15
Second Delta Committee	11.5	1.5	13
Optimal	3.7	5	8.7

At the EU level, (Hinkel et al., 2010) have assessed the risk of and adaptation to sea-level rise in the 21st century under the IPCC's A2 and B1 scenarios. For each scenario, impacts

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[3] At least a factor 10 for all flood-prone areas in the Netherlands.

were estimated with and without adaptation in the form of increasing dike heights and nourishing beaches. The model-based study found that up until the year 2050 impacts will primarily be determined by socio-economic development. In 2100, assuming no adaptation, 780,000 people per annum are estimated to be affected by coastal flooding under A2 and 200,000 people per annum under B1.

Hinkel et al. (2010) estimate the total monetary damage caused by flooding, salinity intrusion, land erosion and migration at about € 15 billion under both scenarios in 2100; damage costs relative to GDP were found to be highest for the Netherlands at 0.3% of GDP (under A2).

Adaptation was projected to reduce the number of people affected by flooding by a factor 110 - 288 and total damage costs by a factor 7 - 9. In 2100 adaptation costs are projected to be € 3.2 billion under A2 and € 2.3 billion under B1; adaptation costs relative to GDP are highest for Estonia (0.16% under A2) and Ireland (0.05% under A2).

These results suggest that adaptation measures to sea-level rise are beneficial and affordable, and will be widely applied throughout the European Union.

3.4 Conclusions

The business case for hydraulic structures indicates that safe life extension of critical infrastructure can be managed using a two-pronged approach. Using cost-benefit analysis in combination with risk assessment an estimate of the optimal (economically efficient) level of protection can be obtained. Once this level has been established the trade-off between the costs of rehabilitation and replacement of individual assets, such as sluices and weirs, can be made. To date risk-based cost-benefit analysis has primarily been applied to dikes as the key flood protection measure. A promising direction for future research would be to extend the methodology to hydrological structures and possibly also other critical infrastructure assets.

Other priority areas for further research include better estimates of exposure of hydraulic structures to environmental conditions across the EU; and the elaboration of possible impacts of changing system requirements (e.g. larger vessels) on rehabilitation/replacement decisions. Furthermore, researching failure rates and establishing degradation functions of different hydraulic structures will be essential for improving the accuracy of forecast future behaviors of hydraulic structures.

3.5 References

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KIND, J. M. 2014. Economically efficient flood protection standards for the Netherlands. *Journal of Flood Risk Management,* 7.

4 Business Case: Wind turbines

4.1 Background

The European Union has set a binding target of 20% of its total energy supply to come from wind and other renewable sources by 2020. To achieve this overall target, over one-third of European electric power demand will have to come from renewables. Wind power is expected to deliver 14-18%, against and estimated share of 7% in 2012.

The shift to wind energy aims to increase overall conversion efficiency and thereby significantly reduce the unit cost of electricity from renewable energy resources. Solutions aimed at increasing the economic return are required to assist owners and operators with reducing the O&M costs of both individual wind turbines and wind farms.

Fatigue is a major consideration with respect to the operation and maintenance of wind turbines. However, as technology associated with wind power is progressing fast, wind turbines can become obsolete at, or indeed well before, the end of its technical life. Therefore, life extension may not always be economically feasible when compared with replacement. Cost-benefit analysis and life cycle cost assessment are therefore paramount in the case of wind power.

4.2 The business case

For the purpose of analysing the business case a generic wind farm comprised of 100 wind turbines is considered. The wind farm is initially operated during 20 years, equalling the design life of the wind farm. Upon completion of the life cycle of 20 years the wind farm is repowered with turbines with identical technical specifications. Under normal operations in the base case two replacements are considered in the business case, i.e. at year 20 and at year 40.

4.2.1 Base case and options

The base case consists of operation of the wind farm until its expected life time has expired, without investing in life extension. Repowering with identical turbines of 660 KW will take place twice during the evaluation period, in year 20 and year 40.

The first option explored in the analysis reflects repowering with 2 MW turbines in the years 20 and 40 (i.e. without life extension).

Furthermore, two life extension options with one single repowering intervention are explored:

i) life extension until year 30 and subsequent repowering with identical wind turbines; and

ii) life extension until year 30 and subsequent repowering with 2 MW turbines in year 30.

4.2.2 Maintenance

For the base case, operating and maintenance (OM) is done predominantly on an ad-hoc basis, in order to minimise production interruptions. In the life extension case, O&M is conducted through a guaranteed (i.e. fixed-price) contract for the remaining life of the wind farm.

Structural elements of wind turbines require inspection of 100% of all frames. Either preventive or corrective solutions are applied to all turbines. Other failure rates are assumed to be constant and all cost risks are assumed to accrue fall to the O&M contractor. Contracted O&M activities also include preventive exchange of wind turbine blades. Disassembled blades can be repaired and stored until they are needed again to substitute other blades that are likely to fail before the end of technical life. Furthermore, gear boxes are also subject to preventive exchange. As with blades, disassembled gearboxes will be repaired and stored until they are needed again to substitute other gearboxes with a high probability of failure before the end of technical life. All wind turbine towers and foundations are inspected and a Condition Monitoring System (CMS) is installed to monitor both elements. This monitoring secures a significant decrease in ad-hoc repairs. CMS will not be required in all turbines.

Previous investments are considered sunk costs in the business case. Investments are made in year one, while repowering is done within one year, without any interruption in productivity. Costs are in constant prices (i.e. zero inflation) and a fixed discount rate of 5.5 percent is applied. Energy prices are assumed to be constant.

4.3 Analysis

Net present value (NPV) and economic rate of return (ERR) were chosen as key economic indicators for comparison of the three options against the base case. NPV represents the sum of the present values of incoming (benefit) and outgoing (cost) cash flows over the lifetime of the wind farm. IRR, the discounted cash flow rate of return, measures and compares the profitability of the investments.

Table 8 Net present value and internal rate of return for the wind turbines base case and three options.

Scenario	Description	Financial		Economic	
		NPV [€]	IRR [%]	NPV [€]	IRR [%]
Base case	Operation during design life of 20 years; repowering with same turbine year 20 and 40	67,490	8.4	140.948	7,9
Option 1	Operation during design life of 20 years; repowering with 2MW turbine year 20 and 40	107,518	8.1	225.835	7,8
Option LE1	Life Extension until year 30; repowering with same turbine in year 30.	175,418	10.6	282.602	9,5
Option LE2	Life Extension until year 30; repowering with 2MW turbine in year 30	234,052	10.6	381.215	9,5

The economic indicators listed in Table 8 suggest that Option LE2 clearly ranks first, both in terms of NPV and IRR. The four figures below compare cumulative income and expenses (NPV) over time for the Base Case (Figure 12) with the Life Extension case (Figure 13), the Repowering case (Figure 14) and the life extension and repowering case (Figure 15).

Figure 12 Cumulative Income and expenses (NPV) – Base case

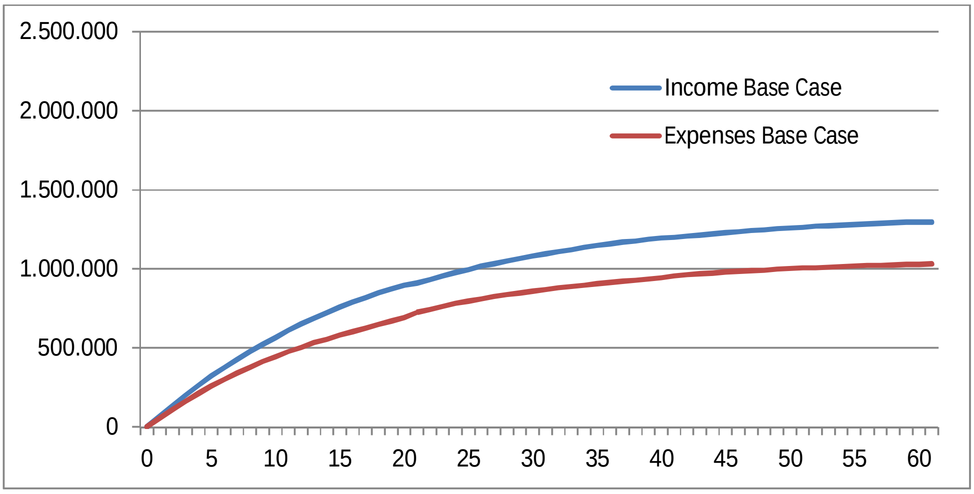


Figure 13 Cumulative Income and expenses (NPV) – Life Extension case

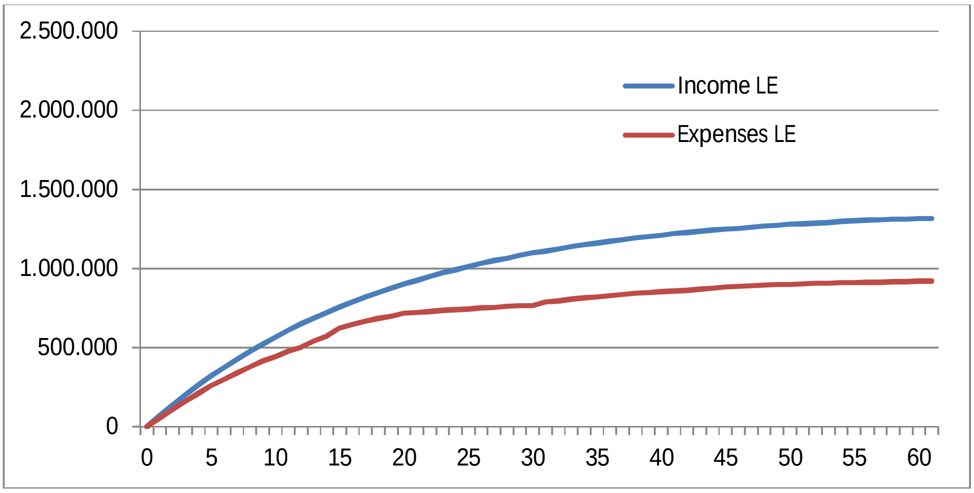


Figure 14 Cumulative income and expenses (NPV) – Repowering (2MW) case

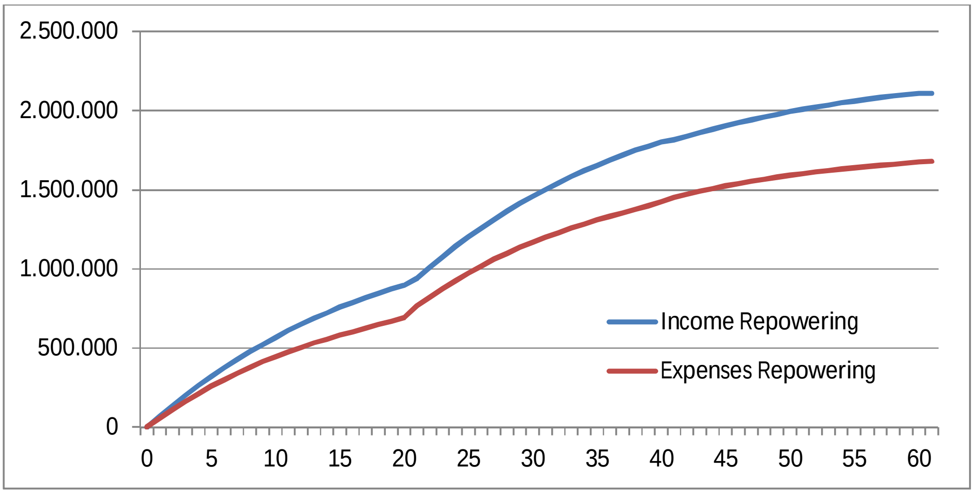
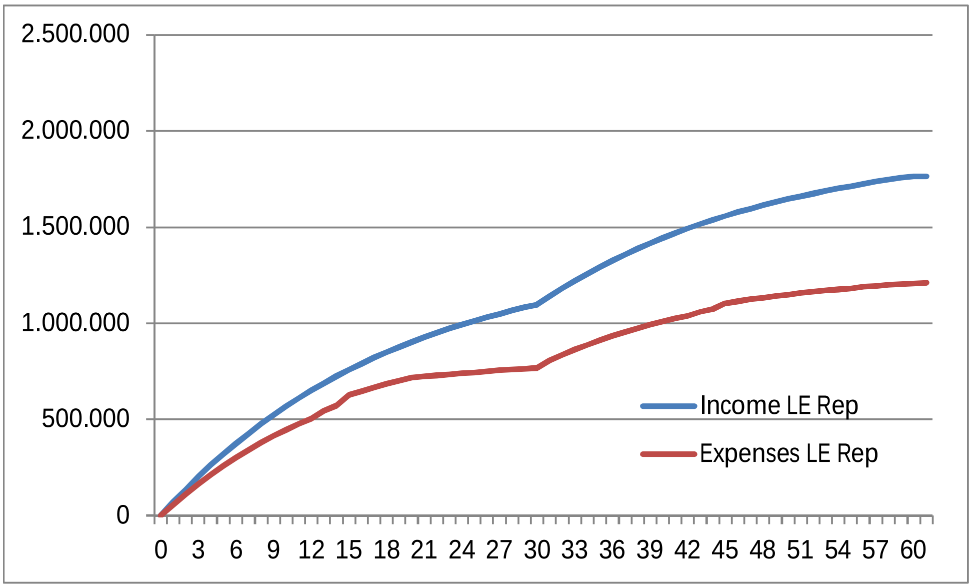


Figure 15 Cumulative income and expenses (NPV) – Life extension and Repowering (2MW) case



4.4 Conclusions

Analysis of the business case suggests that life extension of a wind farm until year 30 and subsequent repowering with 2 MW turbines (i.e. life extension until year 60) has the highest net present value (€ 234,052) and internal rate of return (10.6%).

The impact of changes in failure rates and the associated availability losses potentially have a significant impact on the business case. In the current case the O&M costs are fixed, by means of a contract guaranteeing availability rate for the remaining lifetime of the wind farm.

Further research will be required to translate these preliminary results to generic EU-level recommendations. Refining failure rates and establishing accurate degradation functions of wind turbines remains a research priority. Furthermore, further research is required on safety issues associated with life extension of wind turbines, including on rules and regulations in different EU member states.

5 Business Case: Risk-Based Inspection for prioritization of inspection and maintenance actions in ageing plants

5.1 The Background

Ageing process and power plants in operation today were designed for operating conditions and production use valid at the time of their commissioning. In the process and power industries, plants must work according to unstable and fluctuating capacities dependent on market demands and changes in legislation requiring an increased use of renewable energy sources. Consequently,

- The power generation cost is increasing sharply for fossil power that is indispensable for system stability. The power generation cost for a plant designed for base load operation with some 6,000 full load hours will increase by 100 % if the plant is utilized for 2,000 full load hours only (see VGB PowerTech – facts and figures electricity generation 2013/2014).
- The fluctuating electricity supply requirement increases fatigue type loads and fatigue-related ageing in thermal power plants. Original code based design of the European thermal power fleet at the stage of design did not take into account the future operating modes which can under some circumstances lead to a decline in the forecasted availability and the remaining life time/operation time of plants significantly.
- Similarly, in the process industry, fluctuation in production capacities will lead to unexpected consequences on plant ageing.
- The present maintenance strategies are developed for different conditions and production use.

In both industries, owners require methodologies and tools to describe actual and future ageing of process plants for optimizing O&M costs (e.g. prioritization of inspection & maintenance actions), plant availability and life extension.

Risk Based Inspection (RBI) represents an optimal maintenance concept, using risk as a basis for prioritizing and managing the efforts of an inspection and maintenance program. RBI can be applied to examine equipment such as pressure vessels, piping and heat exchangers in industrial facilities.

RBI assists owners and operators to select appropriate and cost-effective maintenance tasks, increase safety while potentially minimizing effort and cost, produce an auditable system, provide an agreed operating window and implement a risk management tool. The purposes of RBI include:

- Screen operating units of plants to identify areas of high risk
- Provide a holistic approach to managing risks

- Estimate a risk value associated with the operation of each equipment item in a plant, based on a consistent methodology
- Apply a strategy of performing the tasks needed for safeguarding integrity and improving the availability and reliability of the plant by planning and executing the needed inspections
- Systematically manage and reduce the risk of failures
- Provide a flexible technique able to continuously improve and adapt to changing risks
- Provide an appropriate inspection program, ensuring that the inspection techniques and methods consider the potential failure mechanisms
- Prioritize the equipment in a plant based on the measured risk.

The concept of *Technical Life* is very much present in power plants. In many cases at the time when plants, which now fall into the group of mid-life or aging structures, were commissioned, the emphasis was not on life extension. As an example, plants commissioned in the 1970s in Holland, before the commercial market had emerged, were planned for demolition after 25 years. Since the shift to a commercial market for power plants, many of these plants have been kept in operation beyond their initially planned decommissioning dates.

The plants are designed according to standards, i.e. for a certain degree of exhaustion or lifetime consumption, with regards to e.g. Creep and Fatigue (e.g. 200 000h of operation or 150 cold, 1200 warm and 6000 hot starts/shutdowns, respectively). These are very conservative numbers, and appropriate risk assessment, inspection and maintenance can allow us to manage the ageing of these structures by discovering the true state of their components and systems, and allow us to operate them beyond their (conservatively) defined design lifetime.

The concept of *Functional Life* can be explained through certain factors which can render a plant obsolete, or no longer able to fulfil evolving operating or regulatory requirements:

- Sometimes, the requirement for increased capacity leads to the conclusion that further upgrade of an old plant is not economically viable, in comparison to the commissioning of a new one.
- Changing regulation with regards to emissions can also render old plants obsolete, if the modifications required to keep them compliant prove prohibitively expensive.
- The design of certain plants can render them obsolete, with regards to need-response adequacy, when the mode of operation and load cycles change. As an example, some old plants, designed for base-load operation, may be unsuitable by design for cyclic loading. In this case, the merits of life extension through better aging management, inspection and maintenance, should be weighed against the costs of the construction of a new plant better suited for this type of operation.

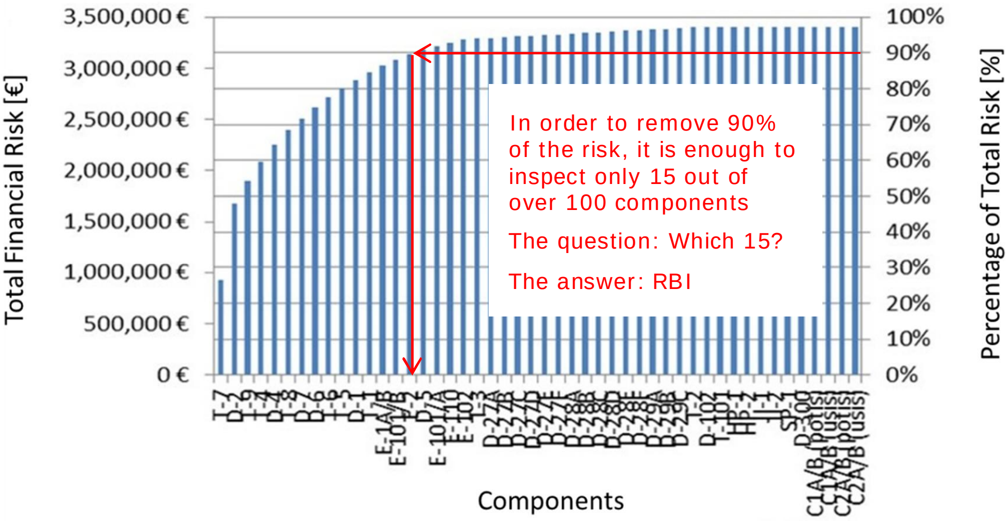
5.2 The Business Case: Applying RBI to prioritize equipment, optimize inspections and reduce risks

In industrial plants, a large portion of the risk is associated with a relatively small number of components, as shown in Figure 16 below.

Typically,

- Approximately 80% of components are of low or negligible risk
- Approximately 15% of the components are medium or medium-high risk
- Approximately 5% of components are high risk

Figure 16: Cumulative risk diagram in an analysis, showing that most of the risk is concentrated in the first few components



In order to remove 90% of the risk, it is enough to inspect only 15 out of over 100 components

The question: Which 15?

The answer: RBI

The risk of the operating equipment is defined as a combination of two separate terms: the likelihood or probability of failure and the consequence of failure.

$$\boldsymbol{Risk = Probability\ of\ Failure \times Consequence\ of\ Failure}$$
$$\boldsymbol{R(t) = Pf(t) \times C(t)}$$

Using RBI, risk assessments of systems and components can be performed. These components and systems are then assigned a risk score and ranked.

The consequence of failure can be assigned a financial dimension, and is calculated as the combined value of the consequences for damage to the failed equipment, damage to the surrounding equipment, loss of production, costs due to personnel injuries and damage to the environment.

$$\boldsymbol{FC = FC_{cmd} + FC_{affa} + FC_{prod} + FC_{inj} + FC_{environ}}$$

Where:

- FC_{cmd} is the financial consequence to the failed equipment
- FC_{affa} is the financial consequence to surrounding equipment
- FC_{prod} is the financial consequence due to production downtime
- FC_{inj} is the financial consequence due to personnel injury
- $FC_{environ}$ is the financial consequence due to environmental damage/cleanup

When the financial consequence is multiplied by the probability of the event occurring, the financial risk or exposure due to said event occurring is obtained.

When a risk assessment is performed, the total financial risk or exposure for all of the components/systems covered by the analysis can be determined. The contribution of individual components, to the overall financial risk in the analysis, is also given.

The implementation of Risk Based Inspection and Maintenance (RBIM) strategies provides the possibility to develop a prioritized inspection plan, which increases the coverage of the high risk components while providing an appropriate effort on lower risk equipment. This strategy allows for a more rational investment of inspection resources.

Some techniques and decision making tools which can be applied as a result of implementing RBI and performing a risk analysis on components and systems are given on the following pages.

5.2.1 Financial Risk – Prioritizing Inspections

The graph showing the overall cumulative financial risk in an analysis is shown below in

Figure 17. The cumulative value of the financial risk is given on the vertical axis, and individual components are given on the horizontal axis.

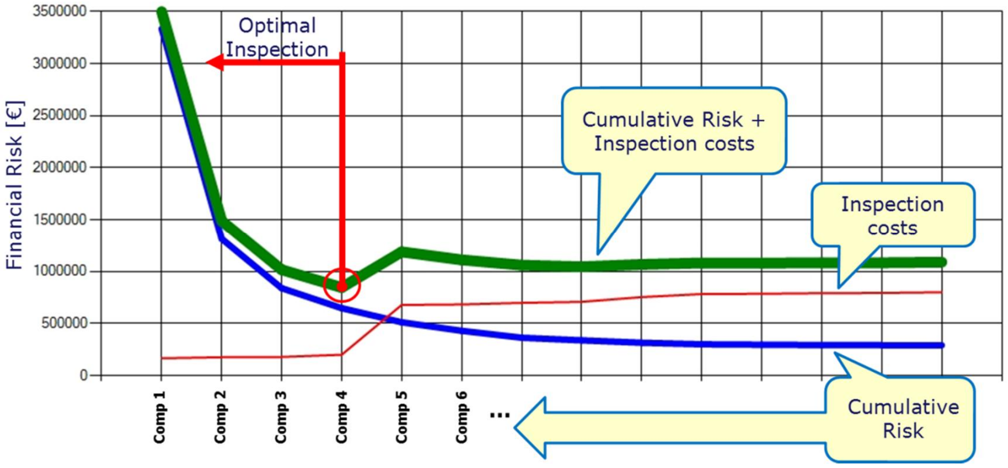
The blue line is the Cumulative Risk Reduction line. This line actually represents an inverted cumulative risk line, and it increases in value from right to left, as each additional individual component contributes to the overall cumulative financial risk in the analysis. The components with the highest individual financial risk contribution are located on the left side of the graph.

The red line represents the increasing cumulative cost of inspections. For each component inspected or replaced, the cumulative cost of inspections increases. At some point, the investment in inspections becomes greater than the cumulative risk reduction, as shown on

Figure 17, where the red line crosses the blue line.

The green line represents the cumulative value line. It is the sum of the cumulative risk and cumulative inspection costs. The minimal point of this line represents the optimal inspection point. The components to the left of this minimal (optimal) point are those which should be inspected, in order to reduce the cumulative risk in the system by the largest amount.

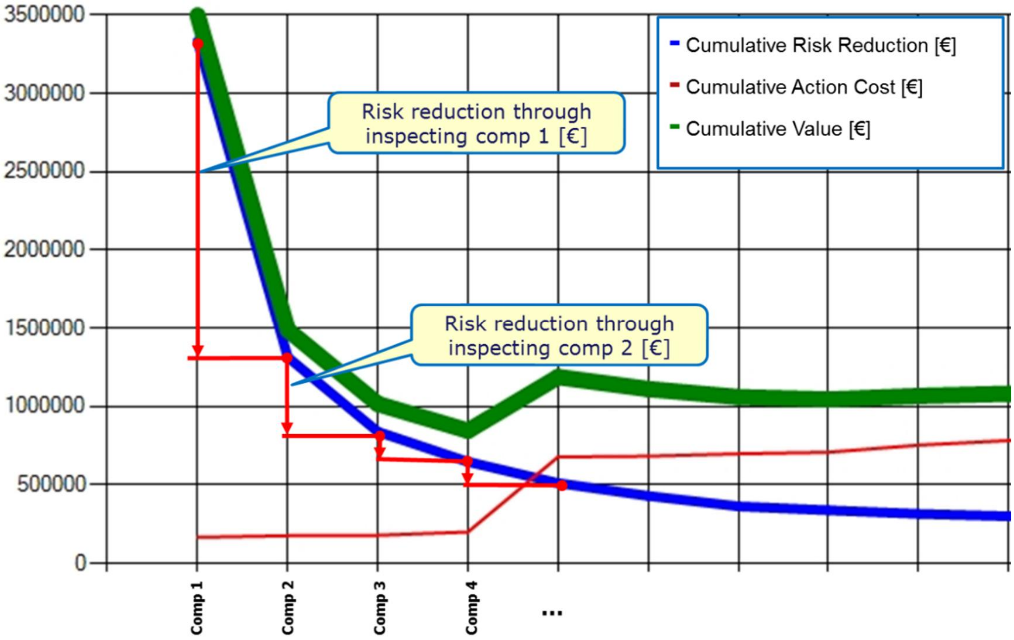
Figure 17: Financial risk in an analysis. The optimal inspection point, encompassing the components with the largest percentage of contribution to the overall risk, is shown



The reduction of overall risk through the inspection of certain components is illustrated in Figure 18 below. As noted in Figure 16, in many systems, most of overall risk in many systems or facilities is borne by a relatively small number of components. In the example below, the greatest reduction in overall risk in the system is achieved by concentrating on the first four components.

The inclusion of financial risk calculations, as defined in e.g. API 581 RBI procedures, aids in the decision making process when it comes to cost-effectively selecting components for action.

Figure 18: Reduction of overall risk through inspection of individual components



5.2.2 Gain-Loss – Component NPV

The gain-loss calculations and diagrams are made possible when a risk assessment is performed for components, and a plan is created for those components. Each component's risk is calculated, applying for example API 581 methodology, at the current time – the Evaluation Date (ED), and at a predefined future time – the Plan Ending Date (PED). For components affected by damage mechanisms which cause degradation over time, this means that the risk at the future plan ending date should be higher than the risk at the current evaluation date, when no action is performed. On the other hand, if inspection and/or maintenance actions are performed before the plan ending date, the component risk may be kept at the current level, or even reduced compared to the current level, depending on the initial state of the component (or our knowledge of the actual initial state, depending on the time, amount and adequacy of Non Destructive Testing performed prior to the evaluation date).

When the current and future risks of individual components are calculated, and the financial dimension of those risks is defined, two scenarios can be considered:

1. Current Risk - Future Risk Without Inspection: this is the case when a component is left to run until the future PED, with no inspection or maintenance action. The risk level of this component will rise accordingly, when affected by damage mechanisms, as the component's condition deteriorates, and the true state is unknown as no inspection has been performed.

$$\boldsymbol{R_1 = Pf(t_{eval}) \times FC - Pf(t_{endnoinsp}) \times FC}$$

Where:

- FC is the overall financial consequence of failure,
- $Pf(t_{eval})$ is the probability of failure at the evaluation date,
- $Pf(t_{endnoinsp})$ is the probability of failure at the plan ending date, without inspections.

2. Current Risk – Future Risk With Inspection: in this case, certain inspections are planned and performed in the period between the evaluation date and the plan ending date, in accordance with the defined risk targets and values of sub-factors governed by each active damage mechanism

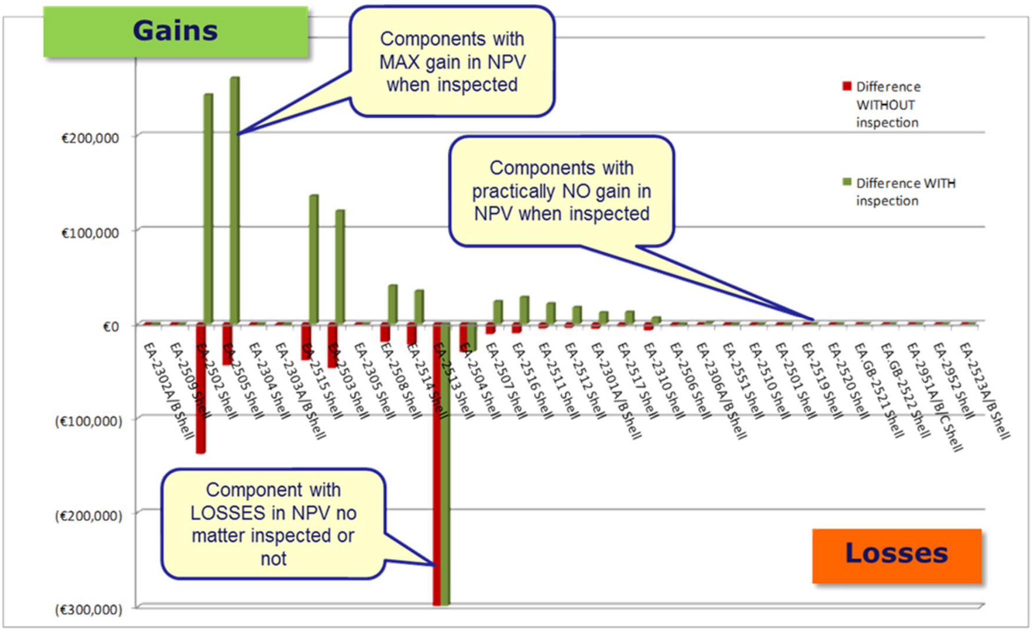
$$\boldsymbol{R_2 = Pf(t_{eval}) \times FC - Pf(t_{endwithinsp}) \times FC}$$

Where:

- $Pf(t_{endwithinsp})$ is the probability of failure at the plan ending date, with inspections.

When the results of these two scenarios are plotted for each component, the overall difference or delta is the component's NPV, expressed through risk, as shown in Figure 19 below.

Figure 19: Gain-Loss diagram, showing individual component NPV



Depending on the active damage mechanisms, type of component and service as well as its observed state at evaluation date (time since previous inspection and scope), several scenarios can arise:

- Certain components will have large gains when inspected, and similarly large losses, if no inspections are performed over the course of the following years, until plan ending date. These components will have the highest gains in NPV after inspection.
- Some components work under specific conditions, where the risk will remain more or less constant in the future, and additional inspections will not reduce it. These components will have practically no gain in NPV after inspection.
- Some components, under the influence of certain damage mechanisms, and operating in certain regimes will have an increase in risk no matter whether inspected or not (e.g. components with identified thinning-type damage mechanisms, nearing the end of their useful service life). These components will exhibit losses in NPV, regardless of performed inspections.

This type of analysis can help in the selection of the correct components for inspections, and eliminate those for which an investment of resources and time for inspection will not significantly alter the risk in the future.

5.2.3 S-Factor

The S-Factor is a calculation which can be applied once the financial risk calculations have been performed for individual components. The S-Factor shows a return on the investment of action (inspection), by dividing the total value of the risk reduction (the difference between the future financial risk without inspection and the future financial risk with inspection) by the cost of the inspections carried out. The larger the S-Factor value, the more worthwhile the actions carried out on the particular component.

Figure 20: The S-Factor

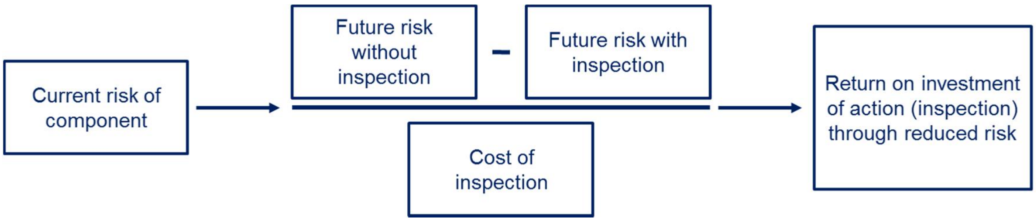
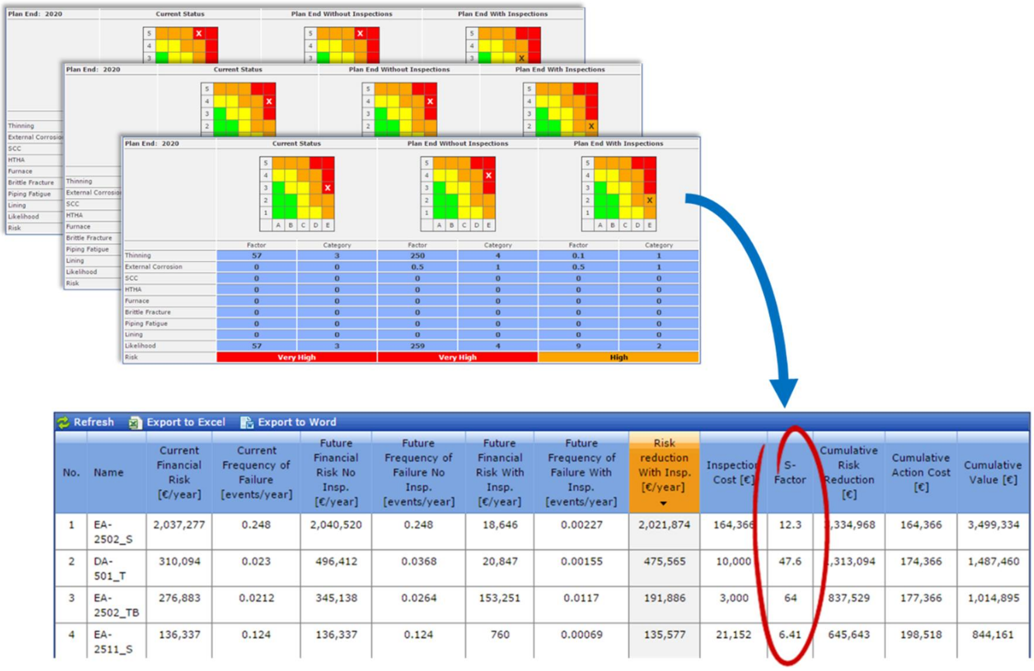


Figure 21: The application of the S-Factor in an analysis through the use of a software tool



Plan End: 2020	Current Status Factor	Current Status Category	Plan End Without Inspections Factor	Plan End Without Inspections Category	Plan End With Inspections Factor	Plan End With Inspections Category
Thinning	57	3	250	4	0.1	1
External Corrosion	0	0	0.5	1	0.5	1
SCC	0	0	0	0	0	0
HTHA	0	0	0	0	0	0
Furnace	0	0	0	0	0	0
Brittle Fracture	0	0	0	0	0	0
Piping Fatigue	0	0	0	0	0	0
Lining	0	0	0	0	0	0
Likelihood	57	3	259	4	9	2
Risk	Very High		Very High		High	

No.	Name	Current Financial Risk [€/year]	Current Frequency of Failure [events/year]	Future Financial Risk No Insp. [€/year]	Future Frequency of Failure No Insp. [events/year]	Future Financial Risk With Insp. [€/year]	Future Frequency of Failure With Insp. [events/year]	Risk reduction With Insp. [€/year]	Inspectio Cost [€]	S-Factor	Cumulative Risk Reduction [€]	Cumulative Action Cost [€]	Cumulative Value [€]
1	EA-2502_S	2,037,277	0.248	2,040,520	0.248	18,646	0.00227	2,021,874	164,366	12.3	,334,968	164,366	3,499,334
2	DA-501_T	310,094	0.023	496,412	0.0368	20,847	0.00155	475,565	10,000	47.6	,313,094	174,366	1,487,460
3	EA-2502_TB	276,883	0.0212	345,138	0.0264	153,251	0.0117	191,886	3,000	64	837,529	177,366	1,014,895
4	EA-2511_S	136,337	0.124	136,337	0.124	760	0.00069	135,577	21,152	6.41	645,643	198,518	844,161

5.2.4 Tangible Benefits – Optimized Inspection Scope

The above mentioned tools and techniques are contributing to the overall savings by reducing the financial risk, or exposure, in components and systems when the appropriate actions (inspection/maintenance) are performed. This is achieved through a reduction of the probability of failure of the equipment in question – either through better knowledge of the true state of the equipment following adequate inspections, or the application of the appropriate preventive maintenance, should inspections indicate a potential problem.

One of the results of applying the above mentioned tools, which gives tangible economic benefits is the ability to create optimized inspections scopes. Some components may be over-inspected, or the owner/operator may be devoting a lot of effort on equipment which does not pose a very serious risk.

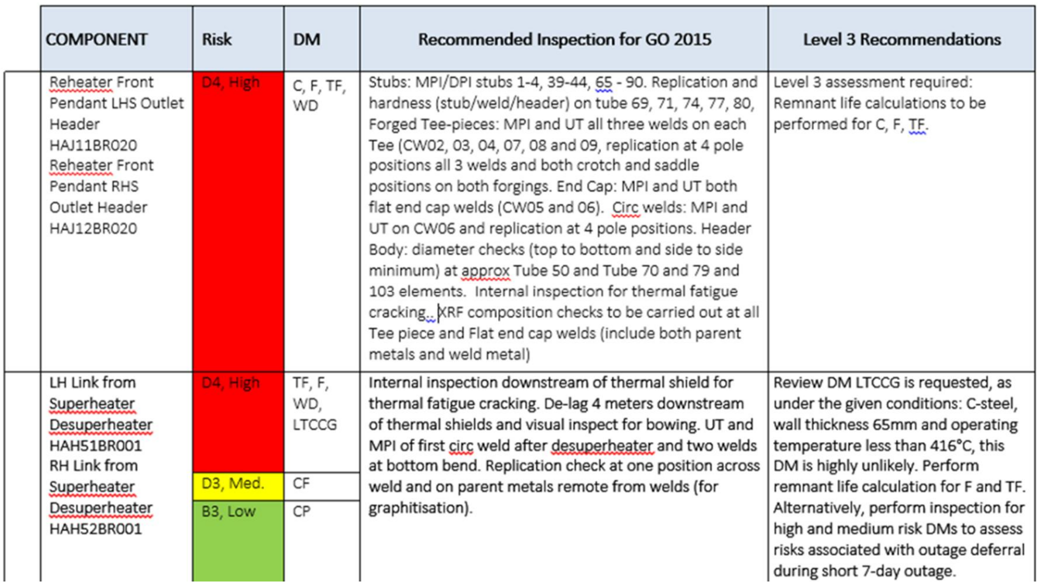
Figure 22: Risk matrix and risk-ranked list of components, following an assessment

LIKELIHOOD							
	5	0	0	0	0	0	0 - 0%
	4	0	3	6	4	0	13 - 24%
	3	0	1	6	1	0	8 - 15%
	2	0	12	1	2	0	15 - 28%
	1	0	15	2	1	0	18 - 33%
		A	B	C	D	E	
		0 - 0%	31 - 57%	15 - 28%	8 - 15%	0 - 0%	54
		CO					

Type	Consequence	Likelihood	Risk
Piping > 16"	E	5	Very High
Column - Top	E	4	Very High
Heat Exchanger - Tube Bundle	E	4	Very High
Vessel	E	3	Very High
Heat Exchanger - Shell	D	5	Very High
Heat Exchanger - Shell	D	5	Very High
Column - Top	E	2	High
Reactor, Regenerator	E	2	High
Vessel	E	2	High
Column - Bottom	E	1	High
Column - Bottom	D	3	High
Vessel	D	3	High
Column - Top	C	3	Medium
Air Cooler	A	4	Medium

After a risk assessment of a system is carried out, and a ranked list of components is created, the owner operator possesses the information with which he can potentially justify a reduction in the scope and/or periodicity of inspections on the much larger number of components located in the medium and low risk areas, while increasing effort on the medium-high and high risk components.

Figure 23: An example of an optimized inspection scope created on the basis of a risk-ranked list obtained from an assessment

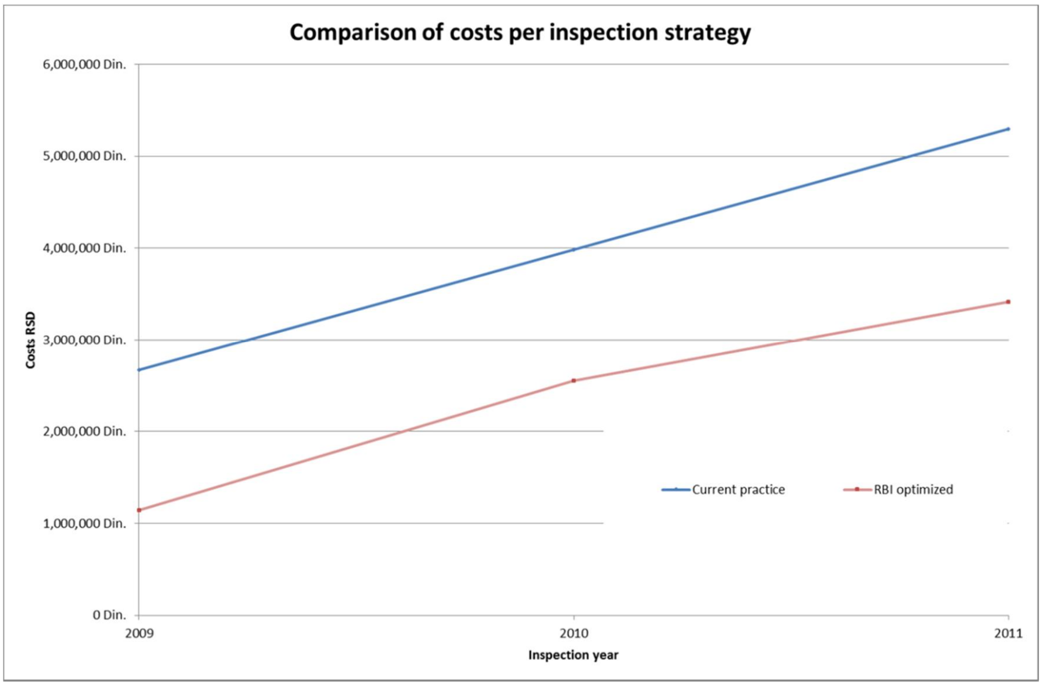


COMPONENT	Risk	DM	Recommended Inspection for GO 2015	Level 3 Recommendations
Reheater Front Pendant LHS Outlet Header HAJ11BR020 Reheater Front Pendant RHS Outlet Header HAJ12BR020	D4, High	C, F, TF, WD	Stubs: MPI/DPI stubs 1-4, 39-44, 65 - 90. Replication and hardness (stub/weld/header) on tube 69, 71, 74, 77, 80, Forged Tee-pieces: MPI and UT all three welds on each Tee (CW02, 03, 04, 07, 08 and 09, replication at 4 pole positions all 3 welds and both crotch and saddle positions on both forgings. End Cap: MPI and UT both flat end cap welds (CW05 and 06). Circ welds: MPI and UT on CW06 and replication at 4 pole positions. Header Body: diameter checks (top to bottom and side to side minimum) at approx Tube 50 and Tube 70 and 79 and 103 elements. Internal inspection for thermal fatigue cracking.. XRF composition checks to be carried out at all Tee piece and Flat end cap welds (include both parent metals and weld metal)	Level 3 assessment required: Remnant life calculations to be performed for C, F, TF.
LH Link from Superheater Desuperheater HAH51BR001 RH Link from Superheater Desuperheater HAH52BR001	D4, High D3, Med. B3, Low	TF, F, WD, LTCCG CF CP	Internal inspection downstream of thermal shield for thermal fatigue cracking. De-lag 4 meters downstream of thermal shields and visual inspect for bowing. UT and MPI of first circ weld after desuperheater and two welds at bottom bend. Replication check at one position across weld and on parent metals remote from welds (for graphitisation).	Review DM LTCCG is requested, as under the given conditions: C-steel, wall thickness 65mm and operating temperature less than 416°C, this DM is highly unlikely. Perform remnant life calculation for F and TF. Alternatively, perform inspection for high and medium risk DMs to assess risks associated with outage deferral during short 7-day outage.

On the basis of the risk-ranked list of components, and appropriate optimized inspection scope is crated, as shown in Figure 23. When the costs of the optimized inspection scope are compared over a period of time with the costs associated with an existing time- or prescription based plan, the reductions in costs become evident.

It should be noted that these reductions, while tangible and represented through real money, are not very great in comparison to the savings expressed through the reduction of (potential) financial risk gained by applying the above mentioned tools (Gain-Loss, S-Factor). The costs of inspection are usually not very high, but the obvious advantage here is the ability to focus on the right components with an adequate scope in the limited time available.

Figure 24: An example of the savings achieved over a period of time through the application of an RBI-optimized inspection scope compared to a prescription-based scope



6 Comparative Analysis of the Business Cases

In short, the main lessons learned from the comparison of the business cases are given below. A more detailed explanation is provided in the following paragraphs (see also annex 1 for a detailed comparison between the business cases).

1. There is a need to share information and knowledge about the applied methodologies across the different sectors, in order to improve aging management.
2. Ageing management can be improved by a focus on data acquisition and improved documentation and document management.
3. The above (2), in combination with appropriate damage modelling and risk assessment, can lead to optimal decision making and improved O&M strategies.

During the SafeLife-X project, a comparison of the business cases was performed at two points:

- At the beginning of the project, when the notes describing the proposed business cases provided by the partners were compiled and compared via semantic analysis, in order to highlight the similarities and differences with regards to the operators' needs, issues tackled by the respective cases, and the applied methods ;
- At the conclusion of the project, when a MCDM analysis was performed over a number of issues which were compiled and sent to the partners responsible for the respective cases. The partners rated the criteria within the individual issues according to the perceived importance for their BC. The issues covered were:

    - The main goals/qualifiers of the BC
    - The initiator of the BC
    - The main work elements of the BC
    - The typical timescale of the BC
    - The main uncertainties associated with the BC
    - Possible areas of improvement within the issues mentioned above, through the application of better aging management

From the initial comparison, it was noted that the issues of owners/operators are similar in a greater or smaller degree across all of the business cases, and that all of them share common concerns (i.e. the increasing costs of O&M for aging infrastructure and structures). The methods applied to tackle these issues were shown to be similar in some respects, and therefore, a cross-sectoral application is possible to a certain degree, as well as cross-case sharing of knowledge, methodologies and information proved to be beneficial.

From the MCDM analysis of the selected issues, performed with the help and input of the partners at the end of the project, underlined the similarities across the business cases and were highlighted in the following areas:

- Maintaining adequate levels of availability within the financial constraints, while maintaining the appropriate safety margins ranked highly on the list of goals for all stakeholders as illustrated in each of the BCs, with the primary initiators of the case/action in all cases being the owners or management of the infrastructure.

- The importance of the goals was reflected in the ranking of the main work elements, with the creation of optimized inspection and maintenance plans while minimizing and maintaining reasonable object technical risks cited as the most important (and most common) criterion across the cases.
- The similarity in uncertainties highlighted across the cases was related to the availability of prior data and information, and to the future unknowns related to load/service changes, be they from environmental changes or changes in the modes of operation.

In all of the business cases, the recommendation for improvements was related to acquiring better data and/or information on the performance and condition of the infrastructure, which would lead to improved O&M strategies. Part of the improvements can be achieved through addressing the issue of ageing infrastructure as a systemic problem, requiring a multidisciplinary approach, focusing on the following aspects:

- Acquisition of monitoring data and improved documentation/document management
- Appropriate damage modelling and risk assessment which will lead to optimal decision making and improved O&M strategies.

7 Concluding Remarks

The analysis of four business cases for safe life extension of built asset demonstrates that these cases can indeed be made. Benefits in the form of significant cost savings can be reaped as soon as the required innovation impacts become available (refer to the SafeLife Extension Strategic Research Agenda and Roadmap for research and innovation).

Cross-case study findings suggest that systematic, 'one size fits all' approaches are feasible with respect to mathematical structural calculation, operational experience and monitoring. Cost-Benefit Analysis (CBA) and Life Cycle Cost Assessment (LCCA) are essential analytical tools for the economic optimisation of life management costs in the cases under consideration.

An important consideration for future analysis is a systemic perspective that can capture network effects as part of the economic analysis. A systemic perspective is likely to give rise to significant additional cost savings. With a focus on systemic optimisation rather than object optimisation it will be possible to identify cost-effective measures that do not necessarily pertain to the object itself. For example, it may be more cost-effective to intervene elsewhere in the system rather than replace or rehabilitate an existing network element. This intervention, for example the construction of a secondary bridge elsewhere in the transport network, will then indirectly extend the life of the main object under study, thus achieving an equivalent outcome.

The systemic approach broadens the perspective of object-oriented asset management in two dimensions. First, a changing focus from one object towards multiple objects. Second, extension from single scenarios to multiple future pathways can significantly broaden the framing of functional life (see also annex 1 for a detailed comparison between the business cases).

A systemic approach starts off with the functioning of a network of objects rather than a single object and would broadly follow four steps

- Step 1 Systems description
- Step 2 Assessment of lifetimes
- Step 3 Scoping of measures
- Step 4 Trading off measures

Following these steps would result in:

- Further evaluation of the systemic approach as a practicable method;
- Better insights in the complex trade-offs between technical life, functional life and system functionality;
- Better understanding of gaps in knowledge and available data;
- Trade-off of investment;
- An evaluation of the degree to which measures can realistically be implemented;
- An improved understanding of feasible adaptation pathways.

A further 'step change' innovation could be achieved by using system of systems. A 'system' can be conceptualized as a dynamic object under a single governance regime, for example a water board responsible for a network of waterways, or a roads and traffic authority responsible for a road network. The notion of a 'system of systems' emerges when simultaneously considering multiple systems with different governance regimes: for example the physical road network and its governance regime (system #1) as well as the physical rail network and its governance regime (system #2), jointly comprising the transport infrastructure system of systems. Finding an optimum in a system of systems is even more challenging.

Annex 1 Detailed Comparison of the Business Cases

Business Cases		Transport infrastructure: Bridges	Industrial infrastructure: Process/Power	Hydraulic Structures	New energy infrastructure: Wind	Gen. Comments
Level of importance (where applicable): * - least important; ** - less important; *** - important; **** - more important; ***** - most important						
1	Description of main goals			Safeguarding adequate functionality at predetermined risk for the lowest costs	Determine criteria and conditions to allow safe operation beyond design life	
2a	Main goals - qualifiers	[x] financial [ ] safety [x] regulatory [x] availability [ ] environmental [ ] other (please explain)	[ ] financial [x] safety [x] regulatory [x] availability [ ] environmental [ ] other (please explain)	[x] financial [x] safety [ ] regulatory [x] availability [ ] environmental [ ] other (please explain)	[x] financial [x] safety [ ] regulatory [x] availability [ ] environmental [ ] other (please explain)	Please mark the qualifier(s) applicable to your business case with an [x].
2b	Please rate the importance of the selected qualifiers	financial (*****) safety (***) regulatory (*****) availability(****) environmental (***)	financial (**) safety (****) regulatory (*****) availability(****) environmental (**)	financial (***) safety (*****) regulatory (*) availability(*****) environmental (*)	financial (*****) safety (***) regulatory (***) availability(****) environmental (**)	Please rate the importance of the above selected items, ranging from * - least important to ***** - most important.
Elaborate/Explain		RBI in ageing bridges concentrates on the demand for condition-based inspection intervals. A demand-driven distribution of the available budget for a large fleet of structures is required.	The main goals of RBI in ageing plants focus around increased safety and availability, through better knowledge of the plant and its risks, by applying a prioritized (optimized) inspection plan. All the while, the process must be compliant, and in line with the demands of applicable regulations. Financial benefit is the main goal, in cases where costs and availability are paramount.	In light of the substantial task in replacing ageing hydraulic structures (250 major structures before 2030) there is a need to time required interventions carefully. Structures that do not meet functional requirements need to be replaced, whereas structures still within their functional design criteria could be rehabilitated if no bottlenecks are thus created. The BC investigates this through a analysis of the object and	Currently the first generation of wind turbine are reaching the end of the initial design life, a stage in which technical failures are demanding increased O&M interventions. By adopting a proactive O&M strategy failure rates can be limited to a minimum, thus maximizing production. The BC illustrates the economic and financial returns of this strategy, which can be adopted in wind turbine parks all over Europe.	If “other” is selected above, please elaborate here, or if further explanation for the choices and respective importance levels is needed.

Business Cases		Transport infrastructure: Bridges	Industrial infrastructure: Process/Power	Hydraulic Structures	New energy infrastructure: Wind	Gen. Comments
Level of importance (where applicable): * - least important; ** - less important; *** - important; **** - more important; ***** - most important						
				the network.		
3a	Who requests, or is responsible for the business case	[x] regulator [x] infrastructure management [ ] engineering dept [ ] other (Please explain)	[ ] regulator [x] infrastructure management [ ] engineering dept [ ] other (Please explain)	[ ] regulator [x] infrastructure management [ ] engineering dept [ ] other (Please explain)	[ ] regulator [x] infrastructure management [ ] engineering dept [ ] other (Please explain)	Please mark the most applicable initiators for your business case with an [x].
3b	Please rate the importance of the selected initiators	regulator (****) infrastructure management (*****) engineering dept. (***)	regulator (***) infrastructure management (*****) engineering dept. (***)	regulator () infrastructure management (*****) engineering dept. (**)	regulator (*) infrastructure management (*****) engineering dept. (**)	Please rate the importance of the above selected items, ranging from * - least important to ***** - most important.
Elaborate/Explain		There are binding regulations in the current inspection process. Some regulations on national level (i.e. Austria) already allow modifications in the inspection process if support by monitoring data and condition assessment results is available.	RBI first needs to be allowed by legislation. When the possibility to implement it is present, the primary interest, can be expressed by top management a) as a means of maintaining or extending current inspection intervals, b) increasing plant knowledge, safety and availability and c) for any incidental and other financial benefits (CAPEX/OPEX).	Infrastructure management is initiating the assessment to rehabilitate/replace an object. Engineering is required for assessment of remaining technical (and functional) life.	Energy producers are faced with increasing costs of production. In cooperation with engineering a proactive O&M interventions is developed. The BC illustrates the economic rationale of this strategy	If “other” is selected above, please elaborate here, or if further explanation for the choices and respective importance levels is needed.
4a	Main work elements (description): e.g. typical contents of the case report – please provide an itemized list.	-Optimized intervention/inspection plan -Ranked Lists -Object technical risks -Object performance -Network performance -Financial optimization	-Optimized intervention/inspection plan -Risk Ranked Lists -Object technical risks -Object performance -Network performance -Financial optimization (e.g.	Assessment of technical life (structural condition, risks of failure) and functional life (performance) of the object and its performance in the (functional) network. -Optimized intervention/inspection plan -Ranked Lists	Assessment of wind farm and its current technical and functional performance. -Optimized intervention/inspection plan -Ranked Lists -Object technical risks -Object performance	

Business Cases		Transport infrastructure: Bridges	Industrial infrastructure: Process/Power	Hydraulic Structures	New energy infrastructure: Wind	Gen. Comments
Level of importance (where applicable): * - least important; ** - less important; *** - important; **** - more important; ***** - most important						
			gain-loss, S-factor)	-Object technical risks -Object performance -Network performance -Financial optimization	-Network performance -Financial optimization	
4b	Please rate the importance of the items given above.	-Optimized intervention/inspection plan (*****) -Ranked lists(****) -Object technical risks() -Object performance() -Network performance() -Financial optimization (**)	-Optimized intervention/inspection plan (*****) -Risk ranked lists(****) -Object technical risks (****) -Object performance(**) -Network performance(-) -Financial optimization (e.g. gain-loss, S-factor)(**)	-Optimized intervention/inspection plan (****) -Ranked lists (action/intervention priority)(***) Object performance (****) Object technical risks (*****) Network performance (****) -Financial optimization (****)	-Optimized intervention/inspection plan () -Ranked lists (action/intervention priority)() Object performance (*****) Object technical risks (*****) -Financial optimization ()	Please rate the importance of the above given items, ranging from * - least important to ***** - most important.
Elaborate/Explain		Regulations for inspection of bridges are in the national standards. Sometimes even regional regulations apply. For this reason there are more than 100 different approaches for this activity in Europe. A best-practice and harmonized regulation is required. The highest priority for bridge owners is a ranking of necessary interventions, the quantification of the	The most important outcome of a risk-based assessment is the optimized inspection plan. Additional items such as component lists ranked by risk, individual component sheets, etc. can serve as tools in the creation of the inspection plan. The elements covering the financial aspects are additional outputs of importance for the top management.	Although assessment of the object is important, its function within the network should equally be evaluated, in order to avoid “bottlenecks” in the network	Inspection methods have to be developed and empirical analysis done to calculate the real design life consumed.	If further explanation for the items and respective importance levels is needed, please elaborate here.

Business Cases	Transport infrastructure: Bridges	Industrial infrastructure: Process/Power	Hydraulic Structures	New energy infrastructure: Wind	Gen. Comments
Level of importance (where applicable): * - least important; ** - less important; *** - important; **** - more important; ***** - most important					
	consequences of interventions and the timeframe for execution. In all these steps availability of the infrastructure and harmonization within the fleet of structures are important.				
5 Typical time scale of the business case	[ ] < 1 year [x] 1-3 years [x] 3-10 years [x] > 10 years [x] other (life time)	[ ] < 1 year [x] 1-3 years [x] 3-10 years [x] > 10 years [ ] other (please explain)	[ ] < 1 year [ ] 1-3 years [x] 3-10 years [x] > 10 years [ ] other (please explain)	[ ] < 1 year [ ] 1-3 years [x] 3-10 years [x] > 10 years [ ] other (please explain)	Please select the typical timescale for your business case with an [x]. If the timescale is different from the provided choices, please indicate it in the field below.
Elaborate/Explain	Due to the fragmentation of the process in Europe on national level there is a wide variety of applications. On international level a detailed inspection every 6 years complemented by an annual visual check and a biennial functionality assessment is the rule. Nevertheless experience has shown that with available budget this plan cannot be executed.	From the practical cases considered, the inspection periods for most components in industrial plants range from 2-6 (in extreme cases from 1-12) years. A risk-based optimized plan is created for this period, and typically reviewed and revised after each outage is carried out.	As TL and FL of hydraulic structure is typically 50 – 100 years the BC also has a very long time horizon. Sometimes simple rehabilitation plan can be quite economically feasible over a rather short period of 5 – 10 years.	Only few products/methods are available today in the market. One scenario would be life extension of design life +10 years.	Please elaborate your choice, if needed, and indicate the timescale, if other than the choices provided above.
6 Main uncertainties in the business case – please provide an itemized list	Bridges are exposed to the environment and are frequently experiencing changes in life loads. The main uncertainty therefore	-effectiveness of performed inspections -certainty and availability of NDT data	Climate change and socio-economic development scenarios can strongly influence FL of the objects and/or the network	Regulation of beyond design life operation is not clear making it very difficult to take a financial decision by the actors.	Please provide the main factors, in your experience, which introduce uncertainties into your respective business case. If

Business Cases	Transport infrastructure: Bridges	Industrial infrastructure: Process/Power	Hydraulic Structures	New energy infrastructure: Wind	Gen. Comments
Level of importance (where applicable): * - least important; ** - less important; *** - important; **** - more important; ***** - most important					
	concentrates on the compensation of these two dominating effects. Furthermore there is major discrepancy between the results of inspection based on individual approach of the inspectors. Still most of these works are considerably subjective. -Environment(*****) -Changes in loads/service(*****) -Experience/knowledge of persons(****) -Socio-economic() -Regulatory uncertainties() -Technical assessment issues() -Lack of previous data(***)	-accuracy of information on component sheets -operator knowledge of plant (design and/or subsequent modifications) -experience of operator engineering/maintenance personnel -Environment() -Changes in loads/service(****) -Experience/knowledge of persons(*****) -Socio-economic() -Regulatory uncertainties(**) -Technical assessment issues(***) -Lack of previous data(*****)	Assessment of the actual technical risks is sometimes difficult to do as these are normally single, specially designed and dimensioned objects -Environment(***) -Changes in loads/service(****) -Experience/knowledge of persons(**) -Socio-economic(*****) -Regulatory uncertainties(**) -Technical assessment issues(****) -Lack of previous data(****)	-Environment() -Changes in loads/service() -Experience/knowledge of persons() -Socio-economic() -Regulatory uncertainties(*****) -Technical assessment issues() -Lack of previous data()	needed, please use the field below to elaborate.
Elaborate/Explain	On average only 50% of the necessary documentation for this process is available. Information about previous inspections and ratings are rare to find. The community is ageing and considerable brain drain is a fact. The new management schemes concentrate on	Inadequate documentation management and a deficit of knowledge or experience of the plant personnel requires more conservative risk assessments. -Documentation about performed inspections, repairs or even design or modification data is sometimes unavailable. -In the case of frequent personnel changes, lack of long-term documented history	Lack of historical data and uncertainties of future service/loads play an important role in calculation of remaining TL and FL. Due to the long TL experience from operators can be acquired from the market/consultancies. Norms and regulations are normally not frequently changes, so are stable over time. Analysis of current		Please elaborate on the main factors introducing uncertainties in your particular business case, if necessary.

Business Cases		Transport infrastructure: Bridges	Industrial infrastructure: Process/Power	Hydraulic Structures	New energy infrastructure: Wind	Gen. Comments
Level of importance (where applicable): * - least important; ** - less important; *** - important; **** - more important; ***** - most important						
		organizational and financial issues and lack the most important components namely engineering and the value of monitoring and testing.	affects the knowledge of the plant in the case of newer personnel. -Plant data, necessary for the assessments, gathered by the operator or other party often contains errors. -In most of the cases, the percentage of erroneous data is 10-15% or more.	technical condition is difficult, also because of lack of historical data.		
7	Which of the above can be improved in your business case by better ageing management?	There is consensus that the entire process has to be improved, which would lead to better utilization of available budgets. Innovative approaches which substitute subjective rating by quantified indicators are desired. This concerns the entire activity chain.	All of the points in item 6, introducing uncertainties into the case, can be improved through better management of documentation, plant design and inspection records, operating history, qualification/audit records and similar. This will lead to less conservative and better assessments, leading to better inspection plans, with the possibility of reduced inspection frequencies – increasing the potential for savings.	When better knowledge of the current status of the object is available, interventions can be better programmed. Better knowledge of network performance and functional requirements can better specify remaining functional life	Better knowledge of actual performance and its change over time (degradation) can better support the improved O&M strategy	
Elaborate/Explain						

Table 1: Overview of inspection intervals in EU countries

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
AUSTRIA				
Basic	variable[4]	variable	variable	Info not provided
External	variable	variable	variable	Info not provided
Internal	variable	variable	variable	Info not provided
Pressure test	variable	variable	variable	Info not provided
BELGIUM				
Basic	3	1	variable	Info not provided
External	variable	1	variable	Info not provided
Internal	1-3	1	variable	Info not provided
Pressure test	not applicable	not applicable	not applicable	not applicable
BULGARIA				
Basic	2	2	not applicable	data not available
External	1	1	1	data not available
Internal	2	2	not applicable	data not available
Pressure test	8	8	8	data not available
CYPRUS				
Basic	2	variable	not applicable	not applicable
External	2	1st 14 months then every 18 months	not applicable	not applicable
Internal	2	1st 14 months then every 18 months	not applicable	not applicable
CZECH REPUBLIC				
Basic	5	1	not applicable	5
External	1	every 3 months	not applicable	data not available
Internal	5	12	not applicable	data not available
Pressure test	9	9	not applicable	data not available
DENMARK				

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[4] Depends on the test level equipments falls into

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
Basic	4	3	6	data not available
External	2	1	2	data not available
Internal	4	2	8	data not available
Pressure test	Not applicable	8	not applicable	data not available
ESTONIA				
Basic	2	1	2	1
External	4	4	2	1
Internal	2	1	2	1
Pressure test	8	8	-	12
FINLAND				
Basic	4	2	4	4 years
External	4	2	not applicable	data not available
Internal	4	4	not applicable	data not available
Pressure test	8	8	not applicable	data not available
FRANCE				
Basic	3	1	variable	3
Periodic requalification	10	10	10	data not available
External	1-3.25	1.5 – 3.25	variable	data not available
GERMANY				
Basic	5	3	5	5
External	2	1	5	data not available
Internal	5	3	not applicable	data not available
Pressure test	10	9	5	data not available
HUNGARY				
Basic	5	3	5	data not available
External	3	1	3	data not available
Internal	5	3	5	data not available
Pressure test	10	9	10	data not available
IRELAND				
Basic	variable	1	variable	variable

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
External	variable	data not available	variable	variable
Internal	variable	data not available	variable	variable
Pressure test	data not available	data not available	data not available	data not available
ITALY				
Basic	10	10	10	data not available
External	variable	data not availble	5	data not available
Internal	10	10	10	data not available
Pressure test	not prescribed	not prescribed	not prescribed	data not available
LATVIA				
Basic	4	4	4	variable
External	1	1	not prescribed	1
Internal	4	4	not prescribed	4
Pressure test	8	8	not prescribed	8
LITHUANIA				
Basic	data not available	data not available	data not available	data not available
External	2	1	4	data not available
Internal	data not available	data not available	data not available	data not available
Pressure test	8	8	not applicable	data not available
LUXEMBOURG				
Basic	variable	variable	not prescribed	data not available
External	1-2.5	1	not prescribed	data not available
Internal	5	2	not prescribed	data not available
Pressure test	10	10	not prescribed	data not available
THE NETHERLANDS				
Basic	1st 4, then 4-6	2	1st 4, then 4-6	variable
External	1st 4, then 4-6	2	1st 4, then 4-6	variable
Internal	1st 4, then 4-12	1st & 2nd 2, then 2-4	1st 4, then 4-12	variable
Pressure test	not prescribed	not prescribed	not prescribed	not prescribed

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
POLAND				
Basic	variable	variable	variable	2
External	3-4	3-4	3-4	3-4
Internal	3-4	3-4	3-4	3-4
Pressure test	6-8	6-8	6-8	6-8
PORTUGAL				
Basic	5	5	5	5
External	5	2 or 5	5	data not available
Internal	5	2 or 5	5	data not available
Pressure test	5	2 or 5	5	data not available
ROMANIA				
Basic	variable	variable	variable	variable
External	not prescribed	not prescribed	not prescribed	not prescribed
Internal	4	4	4	data not available
Pressure test	8	8	8	data not available
SPAIN				
Basic	variable	variable	variable	data not available
External	2-3	2-3	6	data not available
Internal	4, 6,8	4, 6	6, 12	data not available
Pressure test	12, 16	8, 12	not prescribed	data not available
SLOVENIA				
Basic	not prescribed	not prescribed	not prescribed	not prescribed
External	not prescribed	not prescribed	not prescribed	not prescribed
Internal	not prescribed	not prescribed	not prescribed	not prescribed
Pressure test	not prescribed	not prescribed	not prescribed	not prescribed
SWEDEN				
Basic	variable	data not available	6	6
External	1st 4 , then variable	6	6	6
Internal	1st 4 , then variable	6	6	6
Pressure test	not prescribed	not prescribed	not prescribed	not prescribed

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
UK				
Basic	variable	variable	variable	variable
External	not prescribed	not prescribed	not prescribed	not prescribed
Internal	not prescribed	not prescribed	not prescribed	not prescribed
Pressure test	not prescribed	not prescribed	not prescribed	not prescribed
Slovakia				
Basic	Variable	variable	Variable	data not available
External	1	0.25	1	data not available
Internal	5	1	data not available	data not available
Pressure test	10	6	not prescribed	not prescribed

Table 2: Overview of inspection intervals in EFTA and non-European countries

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
NORWAY				
Basic	5	5	5	5
External	5	5	5	data not available
Internal	5	5	not applicable	data not available
Pressure test	5	5	5	data not available
SWITZERLAND				
External	2	1-2	6	not prescribed
Internal	2-12	1-4		not prescribed
Pressure test	not prescribed	not prescribed	not prescribed	not prescribed
CANADA				
Basic	variable	variable	variable	variable
MALAYSIA				
Basic	1.25	1.25	data not available	data not available

Type	Pressure Vessel (years)	Steam boilers (years)	Piping (years)	Tanks (years)
Internal	1.25	1.25	data not available	data not available
Pressure test	10	10	data not available	data not available
USA				
Basic	Variable	variable	variable	variable
External	5	data not available	5	data not available
Internal	Variable	data not available	10	data not available
Pressure test	not prescribed	data not available	not prescribed	data not available
South Africa				
Basic	data not available	data not available	data not available	data not available
External	data not available	data not available	data not available	data not available
Internal	data not available	data not available	data not available	data not available
Pressure test	data not available	data not available	data not available	data not available