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PROCROSS

Development of Procedures for Cross-asset Management Optimisation

Final Report

Deliverable No. 4

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Executive summary

The objective of PROCROSS is the development of optimised procedures for cross-asset management of the total road infrastructure (including all sub-assets like pavements, structures, road furniture etc.). It aims at recommending a holistic road asset management scheme to balance the maintenance expectations of different sub-assets and stakeholders.

Based on a comprehensive investigation, which was carried out in cooperation with a high number of European National Road Authorities (NRA), the current understanding of cross-asset management was brought together providing a basis for the recommended procedures. It is important to understand that the PROCROSS approach is based on cumulated inputs and does not reflect a single approach of one road authority alone.

The Final Report (Deliverable 4) gives a detailed overview of the collected results about the use of strategic targets in the context of road infrastructure asset management, representative indicators, monitoring needs of assets and other important requirements for coordinated asset management approaches. The project revealed that many NRAs focus on different approaches and processes which can be characterized as “Top-down” (from strategic to object level), “Bottom-up” (from object to strategic level) or as a combination of both “Top-down and Bottom-up” (strategic and object level meet midway).

It is recommended to combine the maintenance needs of single assets with the strategic targets into one optimisation procedure. To enable a cross-asset management optimisation, corresponding performance indicators (PIs) must be defined on the strategic level as well as on the object (technical) level. Moreover, it is necessary to understand the translation from strategic objectives to technical indicators and vice versa. These procedures are described in detail and explained by an example using a cost-benefit optimisation approach. The optimisation methodology itself was not the main focus of PROCROSS. Putting together the procedures, mechanisms and understanding of cross-asset management in its various facets all over Europe is the main output of the project. Therefore, the Final Report describes the different steps for the implementation of the recommended cross-asset management procedures and gives an overview of possible barriers.

Acknowledgement

The project team of PROCROSS would like to acknowledge the support of all participants of the Technical Advisory Board (TAB) within the workshops chaired by Prof. Dr. J. Litzka. The intensive and fruitful discussion about cross-asset management procedures provided an essential basis for the success of PROCROSS and enabled a big step towards a future-oriented asset management of the total road infrastructure.

The interviews carried out together with selected National Road Administrations in order to gain in-depth knowledge about the structures and processes for cross-asset management provided very important and essential insights. Therefore the PROCROSS consortium would like to thank all interview partners.

Furthermore, the PROCROSS consortium thanks the ERA NET Road Consortium for funding the research, the PEB and especially the PEB project managers Roland Weber and Thomas Kranz for supporting the project.

Table of contents

1 Introduction

1.1 PROCROSS overview and objectives

One of the key tasks in asset management process is an improved and optimised coordination of all maintenance activities on the different sub-assets according to the expectations and requirements of road users, road operators, road owners and other affected parties. It is a complex process which needs flexible and adaptable methods, the experience of the road owners and operators and a clear definition of the stakeholders' requirements.

The main objective of PROCROSS is the development of optimised procedures for cross-asset management of the total road infrastructure (including all sub-assets like pavements, structures, road furniture etc.). The project aims at a recommendation for a holistic road asset management model to balance the maintenance expectations of different sub-assets and stakeholders.

This is somehow different to the traditional approach in asset management where monitoring and measurement data are used to assess condition levels for each sub-asset in the road transport system more or less separately. Overall life-cycle costs/performance and asset values are of secondary importance within many of the current procedures.

An asset management approach should consider all influencing parameters (e.g. age, environment, materials, deterioration processes, loadings, maintenance policies, etc.) and impacts from a more practical point of view. Different sub-assets (e.g. pavements, tunnels, bridges, culverts, walls, noise barriers, variable message signs, drainage systems, etc.) are incorporated into a combined cross-asset framework through experience and good practice.

The main benefit of introducing such a holistic road asset scheme is to save monetary and non-monetary resources and to minimise the negative impacts from socio-economic, technical and environmental points of view.

The result of the PROCROSS project is a holistic approach for the cross-asset optimisation of maintenance activities on the total road infrastructure. Based on a state-of-the-art investigation, which was carried out in close cooperation with European National Road Administrations (NRAs), the developed procedures will enable the combination of maintenance activities on different sub-assets and consequently reduce all negative impacts and effects on road users and other affected parties under different requirements and expectations.

The results cover an extensive field of application and may be summarised as:

- Survey of the State-of-the-Art to find out good practice in cross-asset management optimisation
- Benchmark of cross-asset management optimisation procedures
- Improvement of the efficiency of asset management of the total road infrastructure
- Assessment of maintenance activities from different stakeholders' expectations and requirements
- Support of the decision makers to underline the necessity of maintenance activities from a holistic point of view
- Provide a basis for the implementation of cross-asset management optimisation procedures

1.2 Method

To achieve the project goals and objectives, a close cooperation between the Consortium and the European NRAs was essential. Thus, the whole project was based on an intensified dialogue approach between interested European NRAs and the PROCROSS Consortium in the form of

- workshops,
- interviews and
- discussions.

The dialogue approach focused on the following main tasks of PROCROSS:

- **Identifying the best practice** of asset management processes and understanding **cross-asset interdependencies** and costs/values to evaluate the impact of maintenance activities on the different sub-assets
- Deducing **monitoring requirements** from NRA needs (Top-down approach) to collect the most important performance indicators (PIs)
- Developing **procedures** for cross-asset management optimisation with consideration of the expectations and requirements of the different stakeholders
- Analysing **efficiency** and **applicability** of the proposed **procedures for implementation**

1.3 Technical Advisory Board (TAB)

For this dialogue, a separate Technical Advisory Board (TAB) was established and chaired by an experienced Technical Advisor (Prof. J. Litzka). The European NRA of the PEB members and other selected countries were invited to participate on this board and to provide the Consortium with the necessary information. During the project, the following countries took part in the board with representatives from NRAs, research institutions and consultants:

- Austria
- Belgium (Flanders)
- Denmark
- Finland
- Germany
- Ireland
- Netherlands
- Norway
- Slovenia
- Sweden
- Switzerland
- United Kingdom

During the project the following TAB Workshops were carried out:

- **TAB Workshop 1**

  The 1st PROCROSS TAB Workshop was held in Ljubljana at the Slovenian National Building and Civil Engineering Institute on 9th and 10th of March 2011. The main topics of the workshop were:
  - Organisation of infrastructure asset management in different countries
  - Identification of existing cross-asset management procedures already in place
  - Investigating and establishing common definitions in cross-asset management
  - Investigating how organisational structure, network type, source of money and coordination among different maintenance work influences cross-asset maintenance activities
  - Identification of stakeholders' objectives in cross-asset management.

- **TAB Workshop 2**

  The 2nd PROCROSS TAB workshop entitled "Effective monitoring of road infrastructure assets" was organised on 7th and 8th of September 2011 at AIT/Vienna, Austria. The aim of this workshop was to elaborate answers to the following questions:
  - What indicators are used for asset management in the different countries?
  - Which indicators or parameters are monitored or measured for different road categories (motorways, national roads, secondary roads, rural roads)?
  - What is the objective of cross-asset management?
  - How is cross-asset management implemented today in the different TAB member countries?

- **TAB Workshop 3**

  The 3rd PROCROSS TAB workshop entitled "Procedures for Cross-asset Management Optimisation" was organised on 4th September 2012 in the context of the 4th European Asset and Pavement Management Conference EPAM 4 in Malmö, Sweden. The aim of this workshop was to elaborate answers to the questions based on the presentation of the developed and recommended cross-asset management optimisation approach:
  - Do you have the same understanding of cross-asset management as shown in the recommended approach?
  - Is the recommended approach a practicable way for cross-asset management of the road infrastructure?
  - Does this approach fit into your organisational structure and how would you implement this solution?

1.4 Definitions

For the assessment of existing and new or advanced cross-asset management procedures it is important to define the terms regularly used within this project. The basis for the following definitions are, on one hand, the current respective literature (e.g. COST354 (2008), PIARC dictionary (2011)) and, on the other hand, the discussions within the Project Team and during the Workshops.

Total Road Infrastructure Asset

The *Total Road Infrastructure Asset* is the comprehensive term for all single assets (pavements, bridges, tunnels, culverts etc.) of the road infrastructure, which are necessary to operate a road under given requirements and pre-conditions (safety, comfort, environment etc.). The assets can be directly linked to the road or can be an independent part of the infrastructure. In the context of this project, the assets which are independent parts of the road will not be taken into consideration.

Asset (also single asset, sub-asset)

The term *Asset* will be used to describe elements and/or components of the *Total Road Infrastructure Asset* (see definition above). A single asset can consist of different sub-elements or components. For example, a bridge consists of the superstructure, edge beams, expansion joint etc., which are sub-elements of the bridge. Furthermore, it is possible to group different single assets from a more general point of view e.g. bridges, tunnels, culverts, etc. may be collectively termed Engineering Structures, whilst road signs, guard rails, lighting may be collectively grouped as Road Furniture.

Stakeholder

In the context of this project, *Stakeholders* are defined as a specific or general group of people which are directly or indirectly affected by the planning, construction, operation and maintenance etc. of the *Total Road Infrastructure Asset*. According to the PIARC-definitions, the *Stakeholders* can be categorized into the following groups:

- Users
- Owners
- Operators
- Neighbours
- Financing body
- Society

Asset Management

Asset Management is the comprehensive term to describe all management activities on one or more *Assets* of the *Total Road Infrastructure Asset*. It refers primarily to maintenance and operation activities, but also to improvement and extension of existing *Assets*.

Cross-asset Management

Cross-asset Management is the combination of management tasks and activities over different *Assets* of the *Total Road Infrastructure Asset* within a pre-defined management process. These tasks and activities can – to various degrees – have technical, economic, strategic and environmental objectives/considerations.

Performance Indicator

Performance Indicator is a comprehensive term indicating the condition of the *Total Road Infrastructure Asset*. Based on COST354 (2008), it can be expressed in the form of a Technical Parameter and/or in the form of an index (dimensionless).

Single Performance Indicator

A *Single Performance Indicator* is a dimensional or dimensionless number related to only one technical characteristic of *an Asset, Sub-asset* or *the Total Road Infrastructure Asset*, indicating the condition of that characteristic.

Combined Performance Indicator

A *Combined Performance Indicator* is a dimensional or dimensionless number related to two or more different characteristics of *an Asset, Sub-asset* or *the Total Road Infrastructure Asset.*

General Performance Indicator

A *General Performance Indicator* is a mathematical combination of *Single and/or Combined Indicators* which describes *a Single Asset* or *the total Road Infrastructure Asset* condition concerning different aspects like safety, environment, etc. (also called *Global Performance Indicator*)

2 Understanding of Cross-asset Management

2.1 Introduction

The idea of cross-asset management is not a "one-stop-shop" solution, but rather a best practice, robust methodology through which the entire road transportation network may be maintained and operated in a safe and efficient way emphasising cost minimisation. The term 'cost' does not necessarily mean the liquidity at any point of time and covers a broader financial aspect (Deix, S., et al. (2011)). The desired benefits in this context consider all stakeholders' expectations comprising direct and indirect i.e. societal costs.

Cross-asset management comprises high-quality information on asset inventory, the condition of such assets, the management strategies, customer perceptions and a definition of strategic targets. Additionally, compared to standard management systems of a certain type of sub-asset (e.g. a bridge management system), cross-asset management explicitly encourages a wider target-oriented asset appraisal.

Each sub-asset's maintenance strategy significantly biases the investment options through their respective risk ratings or rankings. The various hierarchical stages of risk ratings and rankings ranging from expert rating, deterministic assessment and semi-probabilistic and probabilistic assessment have already been investigated in depth for each sub-asset. It is the agreed synthesis of the final risk ratings and rankings that are crucial for the decision-making in a cross-asset management approach. Such an impact, quite naturally, supports centralised and rigorously defined standards of infrastructure maintenance management formats.

When the complete information on an entire network of assets, including its sub-assets, is not shared or the information is retained within different clusters, the decision-making may either have independent components (leading to sub-optimal and non-unique final results), or may be unreasonable. The equilibrium or the minimisation in such cases does not consider all the stakeholders and consequently their expectations and requirements are not reflected appropriately. Even when some information is shared and the assessment of assets ranges wider than traditionally considered objectives, the asset optimisation may become a speculator's optimisation problem with different speculators having different requirements, expectations and possessed information.

It is to be noted here, that the term *maintenance activities* extends to the nature and the frequency of inspections of sub-assets and may include the requirement or the level of training of the personnel in charge of such inspections. Decision-making processes under such a framework allocate resources for capacity expansion, balanced holistically by maintenance, operations, and preservation needs. Consequently, it involves life-cycle costs, constructability, ability to be inspected and maintainability – all of which are directly related to the impact of maintenance-related activities on the sub-assets. In short, the impact of the decisions and related, following activities has a significantly greater magnitude in influencing the final result than those without involving cross-asset management procedures.

2.2 Stakeholders' requirements

With regard to the PIARC definition the stakeholders were classified as operators, users, neighbours, society, financing body and owners. An essential basis for the definition of cross-asset management procedures is the different requirements from the different stakeholders. Thus, it was necessary to focus on these tasks within the TAB workshops. The findings from the TAB 1 on stakeholder objectives can be taken from Table 1:

Table 1: Stakeholders' requirements from PROCROSS TAB 1 (Deix, S., et al. (2011))

Stakeholder	**Objectives and requirements**	
Operators	• Asset management and demand be linked for a vision • Honest competitions for tenders • Clear technical normative • Assured works and payment • Optimise working hours (avoid unnecessary repetition of a kind of maintenance) • Customer satisfaction • Improve cooperation between different units of the NRA • Provide necessary funds at the right time for each sub-asset • Ensure consistent infrastructure operation • Increase safety of road workers • More effective maintenance activities • Value, cash-efficiency • Minimise cost of maintenance	• Good coordination of activities on road network • Good mobility across the road network • Combining activities means spending less time on the road/being exposed to different dangerous situations • No duplications of work on same sections • Take maintenance into consideration at decisions on new constructions • Optimal mobility • Economical/optimal realization of construction investments • Optimal maintenance with respect to the available funds • Keep roads open with as little disruption as possible
Financing body	• Cost-effectiveness • High value of asset • Good ratio for budget/value of asset • Maximize profit • Lower budget for activities to be available • Reduce cost – make them efficient • Low costs for good quality of maintenance • No complaints from users • To get the best for the available money • Equalized Budget • Use money at the right time	• Reduce maintenance costs • Increase effectiveness of maintenance activities • Effective/optimal use of available resources/funding • Maximize return investments over lifetime of network • Minimum requirement for investment • Optimal use of available budget • Better possibility of argumentation against other internal competitors for money (often sections of public households)
Owners	• Effective/optimal use of available resources/funding • A tool to improve understanding of effects of maintenance • Unproblematic system of maintenance • Level of quality of maintenance that covers needs and avoids collisions • Low risk • No surprises • No headaches from: Operator, Financing Body, Owner, Society, Users, Neighbours	• Optimal maintenance planning • Reduce user disturbance • Reduce negative effects on neighbours • Keep infrastructure in good condition • Prolong the service life of structure at minimum costs • Good quality but not too high • No problems with the neighbours • A road network with a high value for the population • Good network for the users of the road (people, economy)

	• Raise the value of asset • Reduce costs • Better distribution of budgets • Optimal maintenance status, condition of asset • Fulfil political/strategic requirements	• Lower overall expenses for maintenance activities • More effective budget allocation • Keeping value of assets
Society	• Keeping optimal mobility by minimal impact on the environment • Avoid wasting tax money • Optimal use of tax payers' money • Less pollution • Fewer (potentially) dangerous situations • Environmental impacts (noise, CO2, aerosols) should be limited • Quality of overall infrastructure → direct effects on economy • Reduce environmental impacts of roads • Reduce numbers of congestion hours → reduction of macro-economic negative effects • Safe infrastructure	• Minimise disruption • Minimise environmental impacts • Minimise costs • Optimal use of existing (limited) budget • Having smooth traffic with as little disruption as possible • Reducing pollution as much as possible • Not working during the night and at weekends • Providing transport infrastructure • Not too high an influence on the environment • Fast transport of people and goods • Well built and maintained infrastructure at low costs
Neighbours	• Unproblematic life next to the road infrastructure • Fast and effective solving of problems • Nothing special except information • Minimize negative effects of road infrastructure • Reduce noise, pollution, etc. • Minimize the impact on the quality of living (noise) and environment (pollution) • Make sure that protective measures are active (noise barriers, functional pavements, etc.) • Less disturbance by repair workers	• Good planning of maintenance → fewer interruptions/less hassle • Low noise • Environmental effects • Minimise nuisance (noise, pollution, disruption, etc.) • Fewer bypasses or other disruptions or harmful effects on their life activities • Good environmental activity (low noise, little emissions) • Small negative influences of the road network on air, people (noise)
Users	• No delays • Smooth traffic • Reduced queues, delays • Minimize disturbance • High quality of the road • Ensure consistent infrastructure for users' needs • Minimise interruption, avoid unnecessary obstacles • Provide reliable infrastructure. Safe journey from A→B • Well maintained roads throughout the year • No or as few as possible road blocks	• Mobility of the road network • Optimise the factor value/money • Safety, efficiency, reliability • Ensure good condition of all sub-assets • Avoid multiple road interventions/closures → reduced user costs (included accident risks) • Traffic flow, not too many construction sites • Less disruption to traffic • Fewer dangerous situations • Optimal mobility

The TAB assessed (by voting) the influencing factors on asset management (AM) and the level of cross-asset management relevance with the results shown in Figure 1.

The owners naturally tend to strive for a system in optimal equilibrium for which the cross-asset optimisation may be lucrative as long as the impacts are assessed in terms of direct investment. On the other hand, the users' requirement may often encompass intangible costs which not only include the cost to the road user, but also the cost to the environment, for noise pollution or even the cost of comfort. Such markers directly affect the perceived level of service and are thus valid weighting parameters in a cross-asset optimisation process.

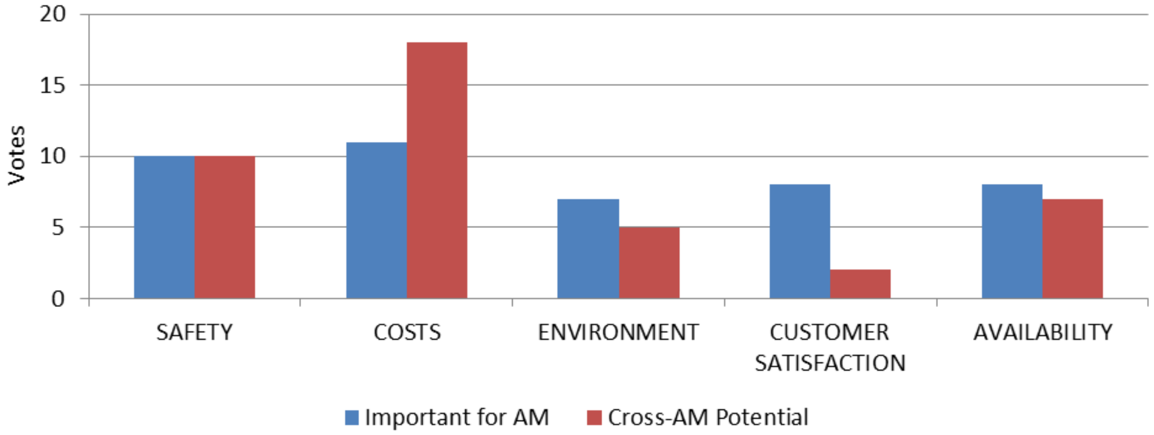


Figure 1: Relevance of stakeholder objectives for asset management and potential for cross- asset management (Deix, S., et al. (2011)).

The neighbours are concerned with safety and environmental aspects, although they may be pliable through legislations and agreements, including existing conditions. The societal expectation very strongly reflects the perceived safety and the perceived level of service of the asset as a whole. Such expectations directly encourage cross-asset management following the perception of the society quite closely. The financing body's expectation, ideally, forms a long term cost minimised solution where a cost prioritisation is expected in line with the available cash flow. However, the expectations of the financing body have increasingly acknowledged the importance of users' perception towards the network as a whole. The road users are mostly concerned by safety, customer satisfaction and availability, which could be seen as part of customer satisfaction. Due to the importance of availability in cross-asset management it is treated separately.

The expectations are usually defined through quantitative and qualitative terms and such juxtaposition is acknowledged and taken into account for cross-asset optimisation. The value of the network of assets is a common but qualitative parameter, with different interpretations of implicit weighting of directly measurable parameters for the stakeholders. The cost is a more direct measure, but the weight of each type of cost is quite different. The environmental requirements are significantly legislated and are often well defined. Consequently, under a common framework of cross-asset optimisation, this term can be standardised. Some factors, like noise pollution, are not necessarily considered in the framework but appropriate legislation-based approaches can uniformly accommodate new environmental factors.

The benefit may be viewed as a qualitative term with multiple interpretations but in reality, within the asset management framework, it can become a defined output. The stakeholders' expectations (see Figure 1) and the strategic targets (formulized by a corresponding weighting) accumulate the benefits. The strategy constitutes the weighting of each stakeholder objective (i.e. safety, costs, environment, customer satisfaction, availability) comprising direct and indirect costs. The difficulty is the allocation of benefits to individual stakeholder objectives.

It is to be noted that although each optimisation problem will prove certain valid solutions, the final decision is not unique and may either be multiple or dependent on the definition and representation of qualitative variables (or both). Consequently, the planning and conceptual design concepts remain exactly the same while considering multiple objectives of requirements of different groups of stakeholders.

2.3 Value, costs and benefit

The value of the asset network is comprised of a number of tangible and intangible factors and their combination. There is no single definition of this combination. The perceived level of safety and service, the real cost of the network, the life-cycle-cost, the environmental cost, the impact on the society and the economy as a whole are the major influencing factors. There is unanimous agreement on using life cycle costs for cost considerations. The costs to the road user and society (indirect costs) have gained a significant acceptance in this aspect. The environmental impact is mostly guided through legislation and is directly reflected through the specific contractual conditions associated with the lifetime maintenance management of the network. The benefit in cross-asset management corresponds to the different stakeholders' objectives and, consequently, the overall benefit is rarely expressed as a unique value of investment required or saved. Rather, the benefit in terms of financial savings can be translated contextually and related perfectly to the expectations of different stakeholders. Such a targeted interpretation and quantification of benefit does not contradict the traditional idea of financial benefit since the benefit of each class of stakeholder is represented in their specified and customised definition allowing them maximum control over a network.

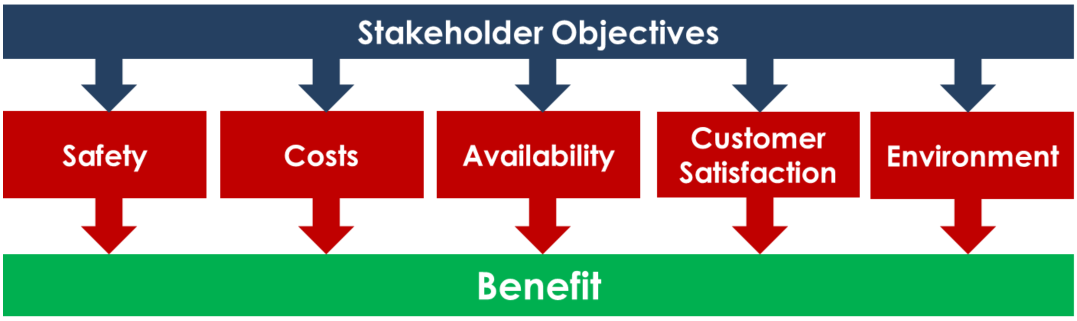


Figure 2: Benefits constituted by the stakeholder objectives.

As shown in Figure 2 the benefit of maintenance activities has to be in coincidence with the different stakeholder objectives. For instance, the replacement of the surface layer of a pavement has a different benefit (improvement of the road safety) in comparison to the replacement of an old, inefficient noise barrier, which will improve the environmental situation only. Although the direct costs (maintenance measures) is one stakeholder objectives the other targets may as well be expressed by monetary values (indirect costs).

For the practical use of the benefit within cross-asset management procedures it will be necessary to calculate the different benefits of the different sub-assets in accordance to the stakeholders' objectives and requirements. The bases for such calculations are the effects of maintenance treatments expressed by technical and/or monetary values, which have to be in coincidence with the different performance indicators and technical parameters to be used. Usually, the effects of maintenance treatments will be defined in form of relative values in comparison to the "do-nothing" or "routine maintenance only" solutions. For instance, the improvement of the safety by the surface layer replacement in comparison to the do-nothing solution or the effect of the new noise barrier in comparison to the bad noise situation with the inefficient old one.

Finally, the sum of all maintenance effects, which are based on the net-wide construction program, define the overall benefit of a maintenance strategy and enable to assess the pre-defined targets (stipulated in form of service level agreements).

This approach shows clearly that the definition of the strategic requirements, performance indicators, technical parameters (indices), target achievement, benefit, maintenance treatments and their monetary and technical effects, network construction program and service level agreements are in close correlation and can be seen as being fundamental to the framework of modern asset management. The following Figure 3 shows this framework and the relationships schematically.

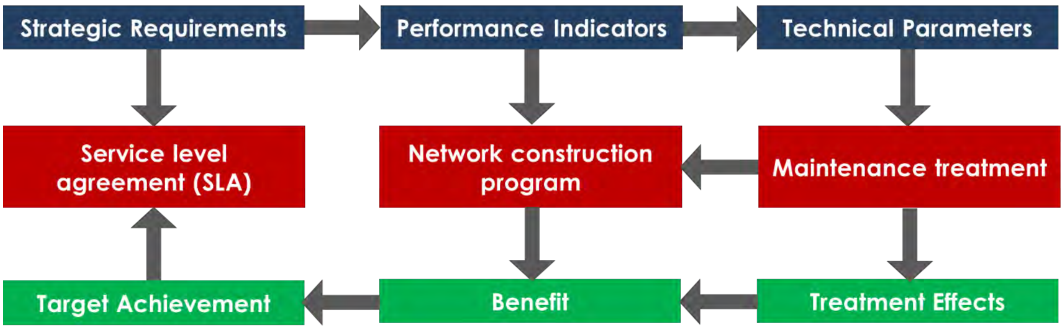


Figure 3: Fundamental framework of modern asset management.

With regard to the given example about the replacement of a pavement surface layer because of sever rutting and an inefficient noise barrier, each element in the framework provides a certain context. This is elaborated as:

Table 2: Example of modern asset management framework definition

Strategic requirements	**Performance indicators**	**Technical parameters**
• Provide safe road infrastructure • Provide silent road infrastructure	• Rutting • Noise emission	• Rut depth under 2m straight edge • Weighted sound pressure level in dB(A)
Service level agreement	**Network construction program**	**Maintenance treatment**
• No road section with more than 20 mm of ruts • No building with imission greater than 65 dB(A)	• Replacement of all pavement surface layers with ruts greater than 20mm • Replacement of all inefficient noise barriers	• Replacement pavement surface layer • Replacement of noise barriers
Target achievement	**Benefit**	**Treatment effects**
• How many sections with ruts greater than 20 mm? • How many buildings with imission value greater than 65 dB(A)?	• Total reduction of traffic accidents in comparison to the situation before • Total reduction of noise disturbance in comparison to the situation before	• Rut depth is 0mm after treatment • Weighted sound pressure level is 55 dB(A) after treatment

For practical calculation of the effects of single maintenance treatments, as well as the benefit of cross-asset maintenance treatment strategies over different assets and the whole network, it is appropriate to use mathematical models which use the same units, so that a normalization of different effects can be avoided (see chapter 3.4).

2.4 Organisation of asset management

The different organisational structures for asset management play a significant role in understanding cross-asset management. The assessment of existing and the definition of new or advanced cross-asset management procedures have to acknowledge the impact of these various organisational structures. In an "ideal" world this influence would be insignificant. However, asset management is not only about the procedures, methods and tools available. The consideration of involved people, roles and different levels of understanding asset needs is another substantial part within asset management.

The organisation of asset management within road administrations or road operators depends on a variety of influencing factors and parameters such as:

- Type of network (motorway, state road network, community road network, etc.)
- Size (length) of network
- Centralised or decentralised decision making structure
- Number and type of assets to be managed within the organisation
- Responsibilities
- Financial preconditions and requirements
- Level of expertise etc.

Based on the collected information from European road authorities, a first general categorization or grouping was carried out according to the responsibilities in:

- Asset-related management structure, or
- Task- or objective-related management structure.

The asset-related management structure is characterized by different administration units, departments or divisions, which cover the management responsibilities for one single asset (pavement, bridge, tunnel, etc.) or a group of assets (e.g. engineering structures). In comparison to this asset-related management organisation, the second group shows a task- or objective-related structure, characterized by units or departments, which fulfil a single management task or function, like planning, financing, operation, maintenance, etc.

In many NRA authorities, a mixture of both categories can be found, with some units or departments being responsible for separate assets (e.g. bridge, pavement, etc.) and some of them holding special (in many cases strategic) tasks (e.g. financing, strategic planning, etc.).

A second grouping of asset management can be carried out from the geographical or topographical point of view. This is strongly dependent on the size of the road network, but also from the number of activities within the management processes. For example, if the operational activities are outsourced, it is not necessary to have a high number of employees at regional branches.

According to the information to be collected, asset management organisation can be organised from the geographical perspective as follows:

- Centralised organisation, where the asset management activities will be carried out mainly in the "headquarter"

- Decentralised or regional organisation, where the asset management activities will be carried out mainly in regional offices

Of course, in many organisations a mixture of both groups can be found, where some asset management tasks will be carried out in the regional branches while others are implemented by the headquarter. In case of a mixture, the strategic tasks could be found mainly at the headquarter level.

An essential question in the context of cross-asset management is related to the governing influencing factors. As already described in the previous chapters, the type and extent of cross-asset management is strongly dependent on the organisational structure of each NRA, how funds are allocated and finally how the different stakeholder expectations are taken into consideration.

The following Figure 4 compares how the NRAs are generally organised and how the responsibilities are defined for asset management issues. With this figure it is possible to "locate" each NRA with a point or circle and to give a clear overview about asset management organisation. The size of the network to be managed is represented by the diameter of the circle and the filling colours are used for different road network definitions (motorways, state road network, etc.).

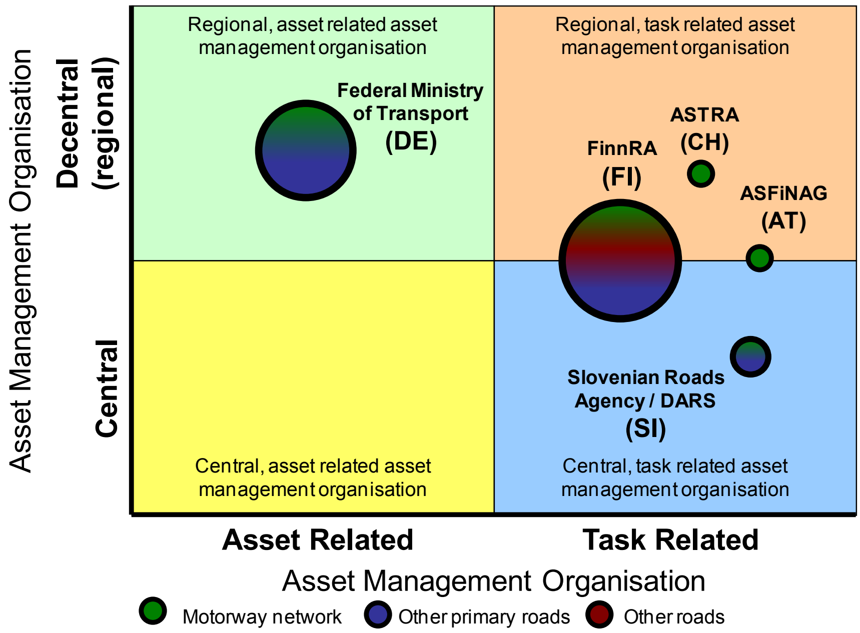


Figure 4: General comparison of European NRAs in the field of asset management (output of TAB) (Deix, S., et al. (2011))

As a summary of the interviews with representatives of NRAs, the following governing influencing factors showed the main impact within cross-asset management:

- Minimizing cost of maintenance operation and optimal use of tax payers' money.
- Optimal economic realization of maintenance investments and effective use of available funds.
- Avoiding unnecessary repetition of maintenance activities.
- Reducing negative effects on neighbours.
- Avoiding multiple road interventions/closures, increase availability and reducing user costs.

2.5 Cross-asset management approaches

2.5.1 Type of approaches

Based on the discussions during the workshops, PROCROSS distinguishes between the following general methods of cross-asset management optimisation:

1. Bottom-up approach
2. Top-down approach
3. Combination of Bottom-up and Top-down

All approaches are valid and consistent in finding an optimum solution based on the preconditions (i.e. strategic requirements, regulatory and legal framework). The difference is merely to be seen in the way the optimum solution is identified and how the translation of strategic targets to technical parameters (object level) is done. The approaches are used to visualize the different concepts and to help road operators and road authorities in identifying the appropriate concept fitting their requirements and prerequisites.

In most of the analysed cases the combination of *Bottom-up* and *Top-down* approaches was identified (Deix, S., et al. (2012a)).

2.5.2 Bottom-up approach

The Bottom-up approach is strongly influenced by the technical assessment of individual groups of assets (object level). Pre-defined technical requirements or thresholds and target-values are the basis for the recommended maintenance activities on each single asset or sub-element to be taken into consideration. Usually, each single group of assets is analysed individually by specific management systems. Those systems facilitate the selection of appropriate maintenance solutions by using different analysis methods under a certain number of given, and clearly defined, preconditions. For finding an optimum solution, the preconditions (set by the NRA or the road operator) must be known and can be of monetary or non-monetary nature (e.g. available budget for a single group of assets over a certain time period). The cross-asset management process is usually not carried out within this level of application, but the results can be used as a basis for the following process of cross-asset "coordination". In many countries, the Bottom-up-process is well established and strongly supported by sophisticated management tools. Many NRAs are organised according to asset-related tasks, so that this approach fits to asset specific management processes.

The results of the individual asset assessments are the basis for the definition of maintenance projects across different types of road assets, where technical and economic performance indicators are used to describe the effects of the measures. Of course, the process of cross-asset coordination brings in the strategic targets (see chapter 3 Stakeholder Requirements) but influences strongly the "optimised" results of single asset assessment. This means that the optimal maintenance solution of the single groups of assets has to be changed often in the coordination process. The consequence is that the recommended construction program of a single group of assets (after coordination) does not necessarily match the single optimum solution. The advantage of the Bottom-up approach lies in a comprehensible technical assessment of single assets. The disadvantage can be seen in the rudimentary consideration of those requirements, which are cross-asset related and need a foresighted adjustment between the different single groups of assets from the beginning (Deix, S., et al. (2012a)).

2.5.3 Top-down approach

In contrast to the above-mentioned Bottom-up approach, this form of resource allocation is based on a central decision which deals with infrastructure on a network level. Seeing as the upkeep of existing assets in Europe consumes a considerable part of road operators' budgets compared to the amount spent on network expansion, significant savings can be achieved if road infrastructure is treated collectively rather than on an asset by asset basis.

The decisions involved in a Top-down approach require a comprehensive understanding of the overall state of the network. Road agencies would allocate certain resources to certain assets with the aim of maintaining or improving their condition, thus producing an overall standard of infrastructure that corresponds to their desired or feasible target. The implementation of such an approach is highly dependent on how the road agencies themselves function: each group of assets (pavements, bridges, tunnels etc.) may, for example, be managed by different departments who compete for resources from the same pot, while some countries manage infrastructure on a regional basis, where assets within the same area are treated collectively, whereas others have a central administration, which greatly facilitates fund allocation with respect to achieving a uniform objective/strategy across the country. Irrespective of how road authorities are structured, the essence of a centralised fund designation is that decisions are made in the pursuit of a strategic target on network-level, rather than dealing with individual assets and how to optimally maintain them within their respective life cycle. Top-down decisions are subsequently made based on strategic requirements.

An example of such an approach is detailed in the work of Mild and Salo (2009), where a decision model was developed for the Finnish NRA (Finnra) with the aim of providing a systematic decision tool that permits fund allocation under the consideration of various objectives. The method explained by Mild and Salo (2009) goes beyond a mere cost minimization tool, as it aims to provide a transparent approach for subjective preferences in resource sharing. The evaluation criteria mentioned therein are road safety, asset value preservation, customer satisfaction and environmental aspects. These are in good agreement with the factors contributing to the so-called global performance indicator defined in COST354 (2008), where indices for safety, comfort, structure and environment are used to describe the overall network and to identify potentially weaker sections. Despite the report's focus on pavements, the idea can be expanded to other assets of the total road infrastructure. Regardless of whether a Top-down approach is implemented on a regional, national or even European level, the maintenance strategy arising from a central resource allocation is the result of subjectively defined guidelines or minimum requirements, such as prescribed safety standards, acceptable environmental effects and desired customer satisfaction. These targets are subject to certain boundary conditions (e.g. restricted funding) and are usually a multivariate function where each variable has an arbitrarily assigned weighting factor that depends on whether the problem is approached from the point of view of the road operator, the user or any of the other stakeholders mentioned above (Deix, S., et al. (2012a)).

2.5.4 Combination of Bottom-up and Top-down

In many NRAs a combination of Bottom-up and Top-down approaches is applied in practice. Strategic targets and requirements are defined by the ministry or the head of the NRA and are compared with the results from the technical assessment of single assets on the object level. The key issue of this solution is to bring the strategic preconditions in coincidence with the technical needs.

In those NRAs, where the combination of Bottom-up and Top-down is used to a wide extent, cross-asset maintenance treatment strategies will be carried out on a level which is situated between the strategic and the object level. This level defines the maintenance activities in so-called “projects”, “schemes” or “planning”, which are essentially an aggregation of the (technical) maintenance needs of the different assets. In most cases this is where strategic preconditions are recognised. However, the projects or schemes are mostly in objection to the view of the object level and can cause conflicts between the strategic department and different technical branches. One of the main reasons for this is the method for the prioritization of projects or schemes, which is mainly carried out on simple ranking and not on a network-wide optimisation.

2.5.5 Discussion of approaches

As explained in the previous sections, there are different reasons for the application of different approaches. It could be seen that the existing organisational structure of an NRA has a certain impact to the applied approaches. For instance, an NRA, which is organised strongly in terms of its assets (pavement division, bridge division, etc.), tends to a more object level oriented approach (Bottom-up) in comparison to an NRA, which offers a strategic department or division for the target achievement of strategic objectives.

Furthermore, it could be seen, that a strongly strategic oriented approach shows a non-negligible risk that asset specific requirements on technical or object level will be omitted or not taken into consideration to the necessary extent. On the other hand, a strong Top-down steering provides clear and comprehensible preconditions for the technical level of the different assets. A critical factor of the Top-down approach seems to be the weighting of the meaning or importance of different objectives and finally of the different assets in the context of cross-asset management. This needs a clear (mathematical) understanding of the relationships between the different strategic targets. Independently from the mathematical formulation such weighting factors are quite sensitive and influence the solution to a wide extent. Furthermore, the optimum strategic solution could be different to the optimum solution on object level if not all technical parameters will be incorporated in the process.

The number of strategic objectives and targets is a crucial factor for all three approaches. If the number is low, the processes within the approaches are much simpler and offer usually a clear understanding of asset management. Many NRAs are using a high number of different performance indicators (technical parameters and indices) at a technical level, which are needed for the selection of adequate maintenance treatments, but not be used for the assessment of strategic targets and requirements and thus not defined in service level agreements. It could be seen, that especially the more Bottom-up oriented approaches tend to a higher number of technical parameters.

If the number of strategic objectives and targets is higher and not all performance indicators are based on clear standards and guidelines, the translation of these pre-conditions into performance indicators and finally into technical parameters indicate certain problems. The compatibility of the elements of the asset management framework is crucial and has to be guaranteed in those approaches, which are more Top-down oriented and hold a high number of strategic objectives and targets.

The investigations and the TAB discussions showed that a clear distinction and the definition of a borderline between the different approaches offer some difficulties. The selection of an adequate approach for a NRA is strongly dependent on the specific requirements of the road network and the general (political) frameworks where and how asset management will be carried out.

Nevertheless, the combination of Bottom-up and Top-down fulfils most of the requirements for the practical application of cross-asset management optimisation. It enables a basis for the combination of the needs of object level as well as the integration of targets and requirements from the strategic level. Furthermore, it provides a platform for the definition or generation of cross-asset maintenance treatment strategies, which potentially form the basis of an optimisation procedure. The discussions and the interviews (see next chapter) showed that many NRAs have already implemented such a platform, where cross-asset management will be (manually) carried out for the definition of the single- or multi-year construction programs. Of course, the combination of Bottom-up and Top-down requires a basis for the communication between the strategic and the technical level which could lead to conflicts and barriers. Especially, these conflicts and barriers need to be incorporated into a holistic approach and can be solved by providing an objective base for the decisions. Furthermore, the number of strategic objectives and targets to be taken into consideration and the number of performance indicators on technical level have a big impact to the complexity of such an approach. The right balance has to be found anyway under the NRA specific asset management framework. This can lead to a more Bottom-up or a more Top-down solution.

Finally, the discussion needs to focus on the term “optimum solution”. An optimum solution on the strategic level is with a high probability different to an optimum solution on object or technical level, because not all technical parameters are usually essential for the achievement of the strategic targets and vice versa. Furthermore, the optimisation routines and procedures are quite different and strongly dependent on the decision tools to be used for the different assets. In the context of cross-asset management optimisation, the optimum solution should be the combination of coordinated maintenance activities, which achieve the targets best and/or minimize the difference between the targets and the actual possibilities taking into account the maintenance needs on object level. Thus, a summation or aggregation of the needs from the strategic level and the object (technical) level is essential. Of course, the optimum solution of cross-asset management will not be the optimum solution neither on strategic level nor on object (technical) level. It will always be a compromise on the objectives to be taken into consideration, which seems to be much more applicable in comparison to imposed provisions from a certain level.

2.6 Interviews

2.6.1 Objectives of the interviews and organisation

One of the critical factors for the success of PROCROSS is the understanding of cross-asset management and cross-asset management procedures as used in practice. As described in the objectives of the project, the procedures should be applicable to different NRAs within Europe and should provide a basis for a more holistic asset management approach (Deix, S., et al. (2012a)).

Based on the investigations within the workshops and the review of current literature, it was decided in mutual agreement with the PEB to go into more detail about practical applications and to perform interviews with pre-selected NRAs. The main objective of these interviews was to get a better understanding of how cross-asset management works in Europe and how strategic targets and requirements will be achieved on different levels of application.

In the context of the preparation of the interviews, a questionnaire was designed as a basis for the execution of the interviews. The questionnaire comprises five main areas of interest, which can be summarized with the following five questions:

- What strategic targets and requirements are used in the asset management process?

- How do you monitor and assess the different assets on an object (technical) level?
- How do you combine the needs on object level with the strategic targets and requirements?
- How do you combine the needs of the different assets?
- Which approach (Bottom-up, Top-down, Bottom-up and Top-down) generally fits your asset management processes?

As already mentioned, the interviewed NRAs were pre-selected in mutual agreement with the participants of the workshops and the PEB. In total the following 5 administrations (4 European NRAs and Transport for London) were interviewed in March 2012:

1. German Federal Ministry of Transport, Building and Urban Affairs, Germany
2. Rijkswaterstaat, The Netherlands
3. Highways Agency
4. Transport for London, United Kingdom
5. Finnish Transport Agency, Finland

The following sub-chapters contain a summary of the interviews performed with the aforementioned road agencies. It has to be stressed that only those road networks which are in the direct responsibility of the respective road administration were included in the interviews. As a result, the main focus became the high-level road network.

Bundesministerium für Verkehr, Bau und Stadtentwicklung

2.6.2 Germany

The interview in Germany was carried out with the German Federal Ministry of Transport, Building and Urban Affairs (BMVBS). The interview partner was Mr. Gregor Schroeder.

2.6.2.1 Organisation and road network

The BMVBS is responsible for financing and maintenance of the federal trunk road network in Germany. The asset management procedures are applied by the states on behalf of the Federal Republic (execution and administrative issues of maintenance, defined by constitutional law). Thus, the 16 federal states are partners in the context of maintenance of the federal trunk road network. At state level, there are usually 3 administrative levels in place:

- State ministry
- Intermediate authority (state authority)
- Building authority

The federal trunk road network in the responsibility of BMVBS consists of the following roads:

- Motorways: 12 800km
- Federal highways: 38 000km

2.6.2.2 Strategic targets and requirements

The BMVBS defines strategic targets in the form of a focused condition distribution, which is based on representative (technical) performance indicators. The distribution is calculated based on LCA, object specific inventory and condition data coming from the technical (object) level assessment of the different assets. Based on this focused condition distribution, the BMVBS estimates the necessary maintenance budget for the different assets over a certain time period. This budget is the monetary framework for the budget distribution to the states and the different assets. The maintenance budget, which is necessary to achieve the pre-defined condition distribution, is stipulated in the Federal Transport Infrastructure Plan (Bundesverkehrswegeplan) which must be adopted by the Federal Parliament.

For the definition of the focused condition distribution, representative (non-monetary) technical indicators (indices) describing the safety and the structural condition of the assets are employed:

- Pavement:
    - Functional index
    - Structural index
- Engineering structures:
    - Stability
    - Safety
    - Durability

The definition of strategic targets according to the availability (user cost model) is under research but not ready for use in the context of strategic target definitions at the moment.

2.6.2.3 Monitoring and assessment

The different assets (pavement, bridges, tunnels etc.) are monitored or inspected in different intervals and to different extents based on national guidelines and standards (e.g. DIN 1076). The framework and procedures for monitoring and assessment of the different assets can be described as follows:

- **Pavements**: High speed condition measurements are carried out every 4 years under supervision of BASt (Federal road research institution) and assessed according to a unified procedure. Pavement performance indicators describe the characteristics of the road surface and the structural condition by using single indicators (rutting, skid resistance, longitudinal evenness, cracking, patching on asphalt pavements, corner breaks and joint damages on rigid pavements), combined indicators (functional, structural) and total condition index, as well as pavement design and age.
- **Engineering structures**: The assessment of engineering structures, which are categorized into bridges, gantries, tunnels and trough structures, retaining structures, noise barriers, etc., refers to stability, safety and durability. During visual inspections (main inspection - every 6 years; interim inspection - every 3 years; special inspections) distresses of the single components are documented and summarized to groups and finally to a total condition index.
- **Other assets**: Assets like drainage, soil and subgrade, planting, furniture/equipment (e.g. lighting, protections systems etc.) and culverts will be monitored during safety inspections only (no periodical condition survey and assessment).

2.6.2.4 Combination of object level needs with the strategic targets and requirements

The strategic targets and requirements are a framework-input to the technical object-related planning of maintenance measures of different asset types on state level, where the coordination of these activities takes place. The framework of the procedure is as follows:

- The construction program (including maintenance, new construction and extensions) is forwarded from the states to the BMVBS on a yearly basis and provides the foundation for the distribution of the budget.
- The distribution key of the maintenance budget to the different states is fixed by the BMVBS based on the length of the network
- The states are free to split their allocated budget among maintenance, new construction and extensions.

Based on this procedure, the combination of object-level needs with the strategic targets can be seen as a two-level procedure, where the BMVBS defines the budgetary framework (by using the technical input from the states) and the federal states are responsible for the execution of the activities according to their needs.

2.6.2.5 Combination of needs of different assets (cross-asset management)

As already mentioned, the combination of needs of different assets will be carried out on state level only. At the moment, the combination is based on engineering judgement, where advanced visualization methods (e.g. strip maps showing the condition information and the recommended maintenance treatments of the different assets) will be used as tools for the engineers to get a holistic view of the maintenance needs of the different assets.

There are no calculations of effects on users and other external costs, and no unified (optimisation) algorithm, which combines different treatments on an objective basis. The current research activities on external costs could be a possible basis for such an optimisation algorithm in the future.

2.6.2.6 Categorization of cross-asset management approach

The current approach of cross-asset management procedures can be categorized as a ***Top-down and Bottom-up solution*** with the following framework conditions:

- The technical (object) level data and information (condition, inventory, etc.) are a basis for the strategic targets, defined in the Federal Transport Infrastructure Plan
- Finally, strategic targets are used as inputs for maintenance planning on state level
- Fixed distribution key for budget distribution to federal states based on the length of the network
- Detailed calculation results of financial maintenance demand for the Federal Transport Infrastructure Plan can be used as input from the federal states for their planning
- No objective algorithm for cross-asset management, which takes strategic targets directly into consideration, is applied at the moment

The whole process for the allocation of maintenance budget according to strategic requirements is a loop, where detailed, asset-specific technical information will be used to generate a budgetary framework for the whole road infrastructure. Afterwards, this budgetary framework will be allocated to the states (by using a fixed key), which can be in contradiction to the basis of the strategic target to a certain extent and makes it necessary to update this process periodically.

2.6.3 The Netherlands

The interview in the Netherlands was carried out with Rijkswaterstaat. The interview partners were Mr. Jenne v.d. Velde, Mr. Bert de Wit, Mr. Max Klok, Mrs. Petra Paffen and Mr. Jasper Schavemaker.

2.6.3.1 Organisation and road network

Rijkswaterstaat is responsible for the financing and maintenance of strategic highways (federal trunk road network), strategic waterways and water systems in the Netherlands. It is the executive organisation that manages the main national infrastructure facilities on behalf of the Minister and State Secretary of Infrastructure and Environment.

The activities are carried out with 10 regional departments, 5 specialized departments, 35 districts and 3 project departments.

The federal infrastructure in the responsibility of Rijkswaterstaat consists of the following assets:

- Federal highways: 3 300 km
- Waterways: 1 700 km
- Water systems: 65 250 km^2

2.6.3.2 Strategic targets and requirements

The 3 key words Costs, Performance and Risk are the key factors for the asset management procedures and for the definition of the targets and requirements. The maintenance of the assets is based on a Service Level Agreement between Rijkswaterstaat and the Ministry, which will be updated every 4 years. The objective of this agreement can be summarized under the wording “To deliver best service to the public at lowest life cycle costs, given public acceptable risk”. Based on these objectives, the service contracts (maintenance contracts) are defined with the regional partners and annually updated. The role of the three different stakeholders can be defined as follows:

- Asset Owner (Ministry)
  - Future orientation of the road network
  - Framework definition (targets, risk and cost)
- Asset Manager (Rijkswaterstaat)
  - Tactical plans (investment strategy, maintenance concept, technology standard)
  - Program management (risk management, performance management)
- Service provider
  - Operations (renewal, expansions, maintenance)
  - Project management and processes

The implementation of the strategic targets and requirements is based on the 4-year asset management program and focuses on the following issues:

- Service level agreements (SLA)
- SLA cycle
- Risk based maintenance planning: RAMS (SHEEP) = reliability, availability, maintainability, safety, security, health, environment, economics, politics)

Different PIs (e.g. congestion, skid resistance, rutting, number of fatalities, accidents, noise, etc.) are used to assess the condition of the assets and are defined in the SLA including thresholds for different road categories.

2.6.3.3 Monitoring and assessment

The different assets (pavement, bridges, tunnels etc.) are monitored or inspected periodically (e.g. pavements: high speed measuring device ARAN). The output of these inspections will be used, on the one hand, for the assessment of SLA (gap analysis) and, on the other hand, for the definition of the maintenance program of the different assets by using LCC analysis (e.g. pavements: IVON-system).

2.6.3.4 Combination of object level needs with the strategic targets and requirements

The combination of object level needs and the strategic requirements are based on a 3-level closed loop procedure (objectives and standards, plans, contracts), which includes a clear allocation of responsibilities and tasks within the holistic decision framework.

2.6.3.5 Combination of needs of different assets (cross-asset management)

The combination of maintenance needs of single assets into coordinated cross-asset treatments is included in the Network Plans, which are part of the asset management procedures.

By using LCC analysis the maintenance needs are defined on asset level and are the input for the Network Plan, which is based on system-engineering concept and consists of the following sub-procedures:

- Optimisation on network parts (by regional departments)
- Unified data management for decision making process and prioritization of (combined) object classes (pavements, bridges, etc.) by using RUPS (program base for combined object class needs and prioritize to match funding sources).

2.6.3.6 Categorization of cross-asset management approach

The current approach of cross-asset management procedures can be categorized as a ***Top-down and Bottom-up solution*** with the following framework conditions:

- SLA with Ministry (4 years) gives strategy and object level needs, which are used for prioritization
- Optimisation is based on a 2-stage approach (combined object class needs, prioritization) within the Network Plan (RUPS) as a part of the holistic asset management procedures
- Assessment of impacts according to the importance of the road (1st step to risk-based approach)

2.6.4 United Kingdom (England)

The interview in the United Kingdom (England) was carried out with the Highways Agency (HA). The interview partners were Mr. Ramesh Sinhal and Mr. Richard Abell (TRL).

2.6.4.1 Organisation and road network

The Highways Agency (HA) is responsible for the operation, maintenance and improvement of motorways and trunk roads in England. It is the executive organisation that manages the main road infrastructure facilities on behalf of the Department for Transport.

The activities are carried out with 2 directorates (network operation directorate, network services directorate) and 9 regional offices.

The federal trunk road network in the responsibility of the Highways Agency consists of the following assets:

- Motorways: 3 000 km
- Other primary roads: 4 000 km

2.6.4.2 Strategic targets and requirements

The strategic targets and requirements for the Highways Agency are defined in

- The Highways Agency's Strategic Plan 2010-15 (see Figure 5), and in the
- Business Plan 2011-12 (see Figure 5).

The Strategic Plan defines the visions, goals and challenges in the context of safety, sustainability and resilience. The plan is a basis for the costumers (users) and sets the course and direction for the business for the next 5 years, translating goals for measures on site.

The Business Plan of the Highways Agency is a framework for the operation, maintenance and the improvement of the network according to efficiency, safety, reduction of costs, sustainability, value for money and the environment. It defines the goals and objectives in a general form, but includes a list of measures, their purpose and how often the performance should be controlled.

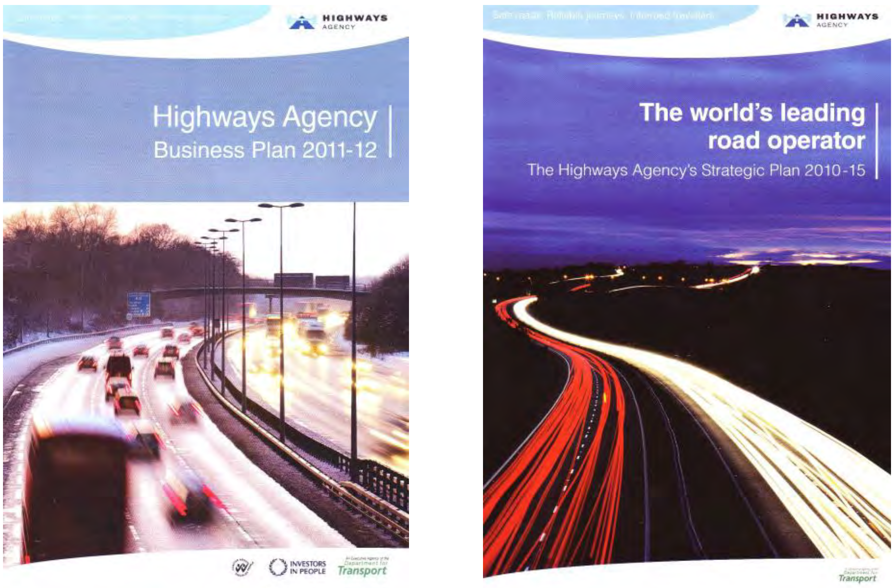


Figure 5: Strategic plan and business plan of HA

Within both plans no requirements according to technical (object and asset specific) indicators are defined.

2.6.4.3 Monitoring and assessment

The main assets (pavement, engineering structures, geotechnical (earthworks) and drainage) are monitored periodically in form of high speed measurements on the pavements and in form of inspections (general – every 2 years; principal – every 6 years) for the engineering structures and other assets.

The outputs of the intensive monitoring are detailed information about the condition and are the basis for the definition of the maintenance needs of different assets. The condition information is assessed (e.g. component conditions of structures are combined to an overall condition index on a scale from 0 – 100) and reported on a standardized basis (e.g. pavements: percentage of sections below thresholds).

2.6.4.4 Combination of object level needs with the strategic targets and requirements

The different assets are measured according to the strategic performance individually. Approx. 400 schemes (maintenance projects) define the programme for pavements, bridges, etc. Hybrid schemes try to treat more assets within one scheme.

The definition of the maintenance schemes is supported by decision support tools like Pavement Management System (HAPMS, whole life cost model; “minimize cost analysis” to hold condition of road network above the “not acceptable” condition) and Structures Management Information System (SMIS, centralised database).

This procedure provides the basis for the definition of the annual maintenance requirements.

2.6.4.5 Combination of needs of different assets (cross-asset management)

The combination of maintenance needs of single assets (schemes) into coordinated cross-asset treatments is mainly based on engineering judgement. The responsibility of this task is on the regional level, where the Managing Agents put the schemes together, define the work to be carried out and allocate the budget to the different single assets (pavement, structures, etc.).

2.6.4.6 Categorization of cross-asset management approach

The current approach of cross-asset management procedures can be categorized from a general point of view as a ***Top-down and Bottom-up solution*** with the following framework conditions:

- The strategic targets and requirements are defined in the multi-year plans, which are used to measure the performance of the assets, tasks and processes. They are used as a general demand for the definition of the maintenance schemes, but do not hold exact (technical) values and targets.
- The asset management tools estimate value for money for each asset type on network level
- Each area (region) defines its own asset management plan. Based on technical information coming from condition measurement and analysis (e.g. LCA for pavements), the needs of the single assets will be defined (schemes) and brought together (engineering judgement).
- The management of the schemes will be carried out on a national basis, which enables a control according to the strategic requirements and targets

2.6.5 United Kingdom (London)

The second interview in the United Kingdom (London) was carried out with the road administration "Transport for London (TfL)". The interview partner was Mr. Leigh Boswell (TfL).

2.6.5.1 Organisation and road network

The community road administration Transport for London (TfL) is responsible for the operation, maintenance and improvement of so-called "A" roads (federal trunk roads) in the greater area of London in England.

The asset management activities for roads are organised in regional/geographic entities in close cooperation with the 33 boroughs of London.

The federal trunk road network (A roads) in the responsibility of Transport of London has a total length of approx. 510 km (carriageway length).

2.6.5.2 Strategic targets and requirements

The strategic targets and requirements of the Transport for London are set by the Mayor of London and are related to the public expectations according to the following topics:

- Traffic flow
- Reducing Congestion
- Safety
- Accident history

Based on the public's expectations, the performance indicators for the strategic targets and requirements are the "Level of Service" (congestion) and the "Level of risk" (skid resistance, rutting, etc.).

The value criteria are as follows:

- Safety – the risk posed to the public
- Functionality – the risk to network performance, including but not restricted to availability and reliability (overall condition)
- Environment – the risk posed to the environment
- Financial – providing WLC (whole life cost) savings considering both direct costs to TfL and indirect costs to the economy

The first three value criteria are used for scoring the risk, the last topic scores the financial requirements.

The following Figure 6 gives an overview of the Highways Asset Management System with the relationships of the different stakeholders and the process from vision, policy & objectives over strategy & planning to operations & delivery and finally ends in the benefits realization & performance measurement.

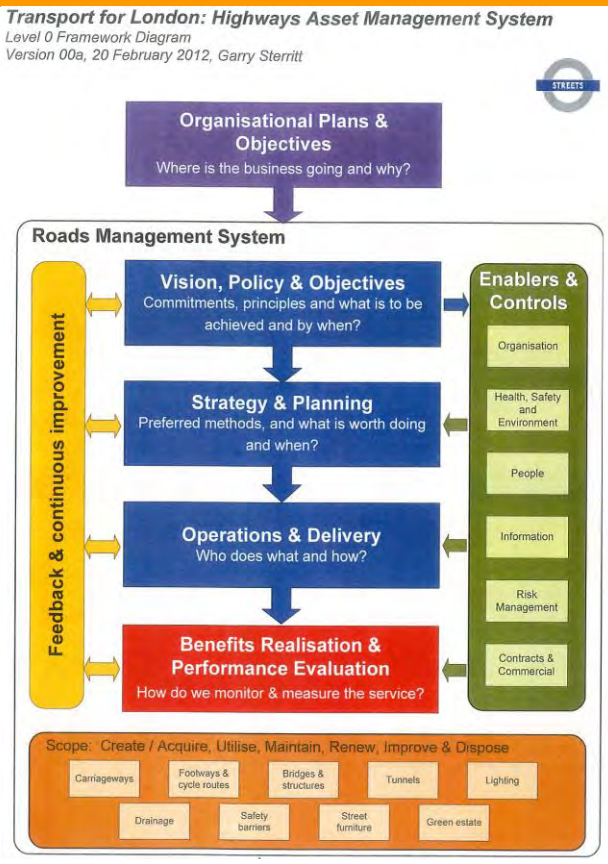


Figure 6: Highway Asset Management process at TfL

2.6.5.3 Monitoring and assessment

The main assets under the responsibility of TfL are carriageways, footways & cycle routes, bridges & structures, tunnels, lighting, drainage, safety barriers, street furniture and green estate. The carriageways and footways are monitored as well as the engineering structures (general inspections and principal inspection).

The output of the monitoring on the carriageways and footways is defined in the NAMS-inventory and is used in the UKPMS (state of repair, SCANNER data, and normalized longitudinal index). The different indicators are combined for the definition of the condition.

Besides carriageways, footways and engineering structures, not much data is available at the moment.

2.6.5.4 Combination of object level needs with the strategic targets and requirements

The combination of object level needs with the strategic targets and requirements is carried out in the form of a risk-based approach including the whole life cost (WLC). The assessment is done for each asset individually (carriageway, footway, engineering structure, etc., but not on drainage) and aims at the “State of good repair”. The output is a list of options for the different schemes for the different assets, which provides the basis for the cross-asset optimisation and the programme to be forwarded.

2.6.5.5 Combination of needs of different assets (cross-asset management)

The combination of maintenance needs of single assets (schemes) into coordinated cross-asset treatments is a risk-based approach, where the value criteria for each single scheme are used to calculate a "Risk Rating Benchmark Value" (score from 0 to 100). This value is used for the optimised prioritization. The prioritized indicative list of schemes is the first stage in the process and is based on:

- Weighted Value Criterion (depending to the type of asset or sub-element)
- Costs based on historic rates
- Prioritized by Risk Rating Benchmark or Safety Risk Rating
- Programmed according to annual budget allocations

For the asset type prioritization / optimisation of different option within a scheme, the following assessment indicators are used and calculated based on LCA:

- Value Criteria (risk rating and risk mitigation) for Safety, Functionality and Environment
- Risk Rating Benchmark
- Weighted Risk Mitigation
- Residual Risk
- Financial Indicator
- Scheme Costs
- WLC (costs)

In the following Figure 7 the program optimisation at TfL is shown schematically. The optimum bundle of the schemes is based on a cross-asset optimisation procedure, where the combination of different options will be assessed and finally selected according to the given requirements.

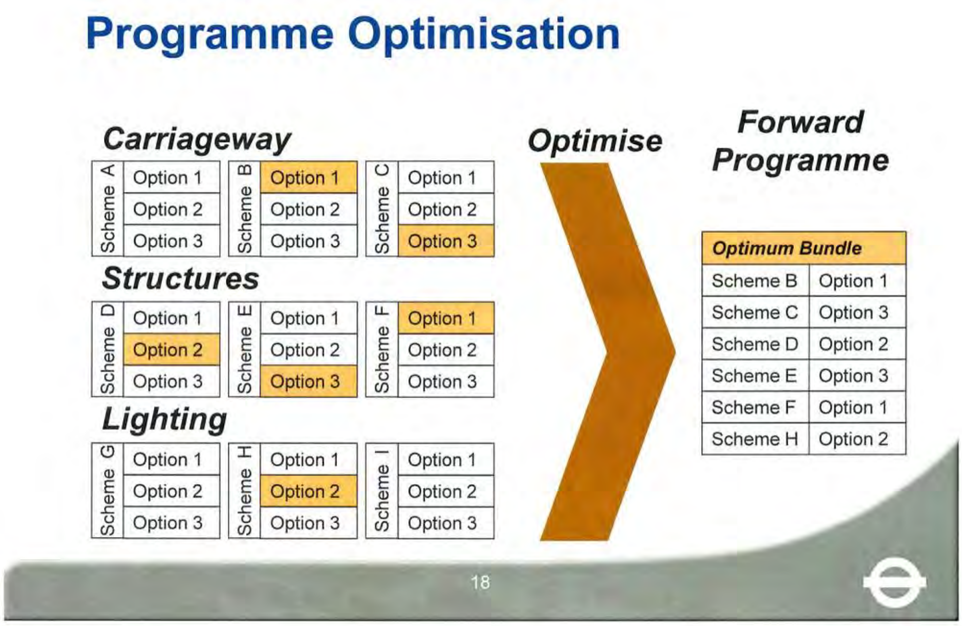


Figure 7: Program optimisation at TfL (preferred options in a scheme are highlighted)

2.6.5.6 Categorization of cross-asset management approach

The current approach of cross-asset management procedures can be categorized from a general point of view as a ***Top-down and Bottom-up solution*** with the following framework conditions:

- The strategic targets and requirements are defined by the Mayor of London and are expressed by different asset specific Value Criteria (Safety, Functionality and Environment) and the annual budget
- The asset management tools estimate the risk of each single scheme option and the WLC (whole life cost) as a basis for cross-asset prioritization / optimisation.
- The program to be forwarded takes asset-specific needs and the strategic targets into consideration and tries to minimize the risk (according to the value criteria) under the given budgetary constraints.

2.6.6 Finland

The interview in Finland was carried out with the Finnish Transport Agency. The interview partner was Vesa Mannistö.

2.6.6.1 Organisation and road network

The Finnish Transport Agency, which is responsible for the public road network, is a Multimodal Transport Agency for the total transport infrastructure (road, rail and waterways). It is the executive organisation that manages the Finnish transport infrastructure on behalf of the Ministry.

The activities are carried out by a central administration in cooperation with 9 regional offices.

The public road network under the responsibility of the Finnish Transport Agency consists of the following assets:

- Motorways: 700 km
- Other public roads: 77 500 km (thereof 28 000 km of gravel roads)

2.6.6.2 Strategic targets and requirements

The strategic targets and requirements for the Finnish federal trunk road network (motorways and other public roads) are codified in form of a Service Agreement with the Ministry, which is updated or upgraded on an annual basis. In total, 13 indicators are defined for all modes, which refer to the key factors: safety and environment, customer satisfaction, punctuality, condition and productivity (internal).

For the road infrastructure assets, the following 2 indicators define the targets and requirements:

1. Proportion of bad conditions of pavements
2. Proportion of bad condition of engineering structures (bridges and tunnels)

These two key performance indicators are based on a uniform classification scale, where 5 is “very good” and 1 is “very bad”. The maintenance backlog refers to assets/ components in a bad condition (class 1 or 2).

Based on the given targets and requirements, the priorities of the overall maintenance strategies are as follows:

- Condition of important road network (approx. 15 000 km)
- Daily maintenance and trafficability of all roads
- Condition of critical engineering structures (bridges and tunnels)

With regard to the different needs of the different stakeholders, the strategy defines strategic goals (well-functioning and safe travel and transport chains, a smaller ecological footprint, technology and new practices have improved the efficiency of operations and made new services possible, etc.) and intermediate goals. Finally, the strategy is directly translated into asset-specific objectives and targets (e.g. primary roads remain good), where requirements like safety, environment and availability are not as important in sparsely populated areas in Finland (e.g. congestion is a problem in one region only).

2.6.6.3 Monitoring and assessment

The different assets (pavement, bridges, tunnels etc.) are monitored or inspected in different intervals and to different extents based on national guidelines and standards. The assets are monitored periodically with high speed measurements on pavements (rutting, IRI) and in the form of inspections (general inspection every 5 years and annual inspection) for the engineering structures.

The monitoring and assessment of other assets is the responsibility of the regional offices.

2.6.6.4 Combination of object level needs with the strategic targets and requirements

The Finnish Transport Agency carries out the combination of object level needs and strategic targets under the following framework:

- Strategic target is prepared at the central administration level to correspond with the target set by the ministry (service agreement)
- Strategic target and funding is then allocated to regions according to their assets, traffic and asset condition, where different regions might have different objectives
- Unified performance indicators are used at all levels and thus they are comparable nationwide (centralised database)
- Results are ensured through a holistic management by objectives (currently four year objectives with annual intermediate objectives)

2.6.6.5 Combination of needs of different assets (cross-asset management)

The combination of maintenance needs of single assets is based on an assessment of each asset individually and brought together for funding and prioritization as follows:

- Long-term funding requirements to keep the status quo are first calculated for all types of assets (pavements, bridges, traffic management, gravel roads, road furniture, etc.)
- The asset-specific needs are summed up, where the total needs are usually higher than the available budget
- If funding is not adequate, the priority order is as follows:
    - Routine maintenance of all roads
    - Traffic management
    - Ferry services

- Pavement of important roads (trunk and main roads, other with AADT > 3 000 vehicles/day)
- Road marking and important furniture
- Critical engineering structures (bridges, tunnels)
- Low volume roads get minimum funding

2.6.6.6 Categorization of cross-asset management approach

The current approach of cross-asset management procedures can be categorized as a ***Top-down solution*** with the following framework conditions:

- Strategy comes from the ministry in form of a service agreement
- Performance indicators define the asset-specific targets (maximum proportion of assets in backlog on all levels)
- The requirements and targets are directly introduced to all levels and define the maintenance activities
- Issues like environment and safety will be managed at the technical level

2.6.7 Summary of the interviews

The following Table 3 gives a first impression about the different road types, which fall under the responsibility of the interviewed NRAs. It can be seen that most of the road networks can be described as the high level road network (federal trunk road network) with the exception of Finland, where besides the trunk roads, other roads including a large network of gravel roads are also managed by the Finnish Transport Agency (Deix, S., et al. (2012a)).

Table 3: Road class overview

Road class	DE	NL	UK	FI
Motorways1)	●	●	●	●
Other primary roads2)	●	●	●	●
Other roads3)				●
Gravel roads (as part of the other roads)				●

1)...........Roads with more than one lane in each direction, separated carriageways (mainly) and level free intersections.
2)...........Arterial roads with one lane in each direction (mainly), no separated carriageways (mainly) and level or level free crossings.
3)...........All other roads.

The lengths of the concerned road networks can be taken from the previous chapters. The smallest network is the London trunk road network with approx. 510 km in comparison to the road network of the Finish NRA with more than 78 000 km of different road types.

Apart from the different road types, the organisational structure of the NRA with respect to asset management was also considered during the interviews. The following Table 4 provides an overview and shows that the interviewed NRAs offer a de-centralised organisation, where the execution and the management of maintenance activities is carried out by the local branches.

Table 4: Organisation of NRAs

Unit	DE	NL	UK (HA)	UK (TfL)	FI
Head (central) office	1	1	2	1	1
State departments / regional offices and other departments	16	9	9	33	9

One of the decisive factors for cross-asset management and finally for the definition of cross-asset management optimisation procedures are strategic targets and requirements. The interviews showed that in all NRAs strategic targets and requirements are defined either in the form of strategic plans or service agreements (between the agency and the Ministry). An overview of the strategic requirements and targets and their use in the asset management processes can be taken from the following Table 5.

Table 5: Strategic requirements and targets

Definition of asset management strategies	DE	NL	UK	FI
Strategic requirements and targets defined	●	●	●	●
Strategic plans or service agreements in place	●	●	●	●
General description of requirements	●	●	●	●
PIs with targets or thresholds	●	●		●
Transfer of strategic PIs to object level	○	●	●[1]	●

●...........existing approach
○...........partially existing approach
●[1] ....at TfL

Different strategic PIs (with or without targets or thresholds) are the basis for the definition of the strategic requirements in the interviewed agencies. One exception was the HA (not TfL, see Table 6), as they do not (yet) transfer the technical performance indicators to a strategic level. In general, the condition-related values are usually based on the technical assessment and the estimated maintenance needs of the different assets, which will be brought together by using different procedures. The definition of the strategic requirements by using technical performance indicators enables the transfer from the strategic level to the (local) object-specific level of application.

Most of the road assets of the interviewed NRAs are monitored at a high level. The output of the condition surveys and inspections are a high number of different indicators and parameters which are used, on the one hand, to plan the maintenance activities at an object level and, on the other hand, to define strategic targets and requirements (strategic PIs).

The following Table 6 gives an overview of the monitoring and assessment procedures, which are used in the asset management approach of the interviewed road agencies.

Table 6: Monitoring requirements and assessment of condition

Monitoring requirements	DE	NL	UK	FI
Monitoring and assessment of pavements (PIs, thresholds)	●	●	●	●
Monitoring and assessment of engineering structures (PIs, thresholds)	●	●	●	●
Monitoring and assessment of other assets (PIs, thresholds)	○	●	○	○
Transfer of monitoring results into strategic targets and requirements	●	●	●[1]	●
Use of monitoring results for the planning of maintenance activities	●	●	●	●

● ....existing approach
○ ....partially existing approach or under development
●[1] ....at TfL

The procedures for the combination of strategic requirements and tasks with maintenance needs at an object level strongly depend on the organisational structure of the respective NRA and the general asset management approach (Top-down, Bottom-up, etc.).

In general, in those agencies where only general requirements and targets exist, the object level maintenance needs mainly define and influence the maintenance programs. In administrations, where clear pre-defined standards and thresholds must be fulfiled, the object level maintenance needs have to be adapted according to these frameworks so that the maintenance program is a (optimised) combination of strategic and object level requirements.

The analysis of the combination procedures between object level maintenance needs and strategic targets/requirements enables to define the type of approach (Top-down, Bottom-up, Top-down and Bottom-up). An overview of the transfer and combination levels can be seen in Table 7.

Table 7: Combination object level needs with the strategic targets and requirements

Level of transfer and combination	DE	NL	UK (TfL)	FI
General combination of strategic targets and requirements with object level maintenance needs	●	●	●	
Specific combination of strategic targets and requirements with object level maintenance needs (complex combination procedures)		●	●[1]	
Strategic requirements and targets transferred to object level only				●

●[1] ....at TfL

Beside the combination of strategic and object level, the coordination of maintenance measures is another decisive factor in the asset management process. At the moment, most European countries combine the needs of the single assets (pavement, bridges, tunnels, etc.) by using engineering judgement, taking into account strategic requirements (e.g. availability) to varying extents. In some countries a more sophisticated optimisation approach (e.g. analysis of cross-asset treatment strategies) is under development, which enables a better and more objective assessment of possible solutions and integration into existing processes and procedures.

The following Table 8 shows the level of application of procedures for the combination of maintenance needs of different assets.

Table 8: Combination of needs of different assets (cross-asset management)

Level of transfer and combination	DE	NL	UK	FI
Combination based on engineering judgement	●	●	●	●
Combination procedures based on analysis		●	●[1]	
Decision support tools for combination procedures	o	●	●[1]	

● ....existing approach
o ....partially existing approach or under development
●[1] ....at TfL

In Table 8 it can be seen that only Rijkswaterstaat (Netherlands) and Transport for London (UK) have a procedure and a system in place that enable them to assess and finally prioritize combined object classes.

With regard to the detailed information about the asset management procedures of the interviewed NRAs, it is possible to use the categorization described in Chapter 2.5,emphasizing the cross-asset management approaches according to the Direction of Decision:

- Top-down approach: the strategic targets and requirements define the maintenance measures at object level to a wide extent; the maintenance needs of the single assets have to be subordinated to the strategic targets and requirements
- Bottom-up approach: the maintenance needs of the single assets are the decisive factor in the decision process; the strategic targets and requirements derive directly from the object level

- Top-down and Bottom-up approach: strategic targets and requirements meet the maintenance needs of the single assets in the middle of the decision process; the decision process is a closed loop of Bottom-up and Top-down.

As already mentioned, the following classification in Table 9 is a general estimation, which can be more complex in detail.

Table 9: Classification of cross-asset management procedures

Class	DE	NL	UK	FI
Top-down				●
Bottom-up				
Top-down and Bottom-up	●	●	●	

As shown in Table 9, the majority of the interviewed road agencies could be classified according to the *Top-down and Bottom-up* approach. As already mentioned, the approach strongly depends on different influencing factors and their respective importance. As an output of the investigation, the following main factors can be listed according to their importance for cross-asset management:

- Organisation of road agency (central, de-central, number of staff, etc.)
- Field of responsibility of road agency (number of assets, type of assets, etc.)
- Availability of strategic targets and requirements (SLA, strategic plan, etc.) and definition of PIs
- Method of budget allocation
- Contracting
- Data availability, monitoring and methods of object level analysis

3 Cross-asset Management Procedures

3.1 Overview of approach

Both approaches, *Bottom-up* and *Top-down*, reflect the different requirements from the object level and from the strategic level. However, the focus and the guiding objectives for the decision making process are different:

a.) Bottom-up: Technical parameters and object level requirements govern the maintenance planning process on a project and network level. The downside of this approach is that strategic objectives are inferred from technical parameters which are not easily understood by all stakeholders. Individual sub-asset specific needs will overrule cross-asset management potential.

b.) Top-down: Strategic decisions (objectives) govern the maintenance planning on the network level and on the object level. The downside of this approach is that individual needs and objectives as well as benefits (cost saving potential) on an object level will be overruled or missed. Simplified performance indicators miss the range and diversity of recognised effects.

Many road administrations use a combination of the two approaches. The reasons for this are sometimes historical, sometimes rational for avoiding the downsides. In order to benefit from the advantages of both approaches and avoid the disadvantages, PROCROSS identified a cross-asset management procedure. This procedure connects strategic targets with object needs and is therefore well placed in between the different layers (see Figure 8).

Of course, to enable a cross-asset management optimisation, corresponding performance indicators (PIs) must be defined on the strategic level, but also on the object (technical) level (Weninger-Vycudil, A., et al. (2012)).

The difficulty of this approach is the transformation of strategic targets into technical performance indicators (PIs); these are defined as numerical values (target function or constraint) within the optimisation process. Not all strategic targets allow such a transformation, so that indirect indicators must be applied for different aspects (e.g. definition of riding comfort in the form of vehicle operating costs (VOC), definition of traffic safety in form of accident risk or accident costs). On the other hand, the effects of maintenance treatments have to connect to achieving the strategic targets. The decisive factor on the object level is the availability of data for the different types of assets and the mathematical relation between the effects of the measures and the respective PIs (e.g. effect of a maintenance strategy on accident risk or on VOC over a certain time period).

This translation between strategic targets, object requirements, maintenance measures into compatible performance indicators seems to be the key to cross-asset management in particular. Only this compatibility enables an optimisation approach and a communication between the strategic and the object (technical) level.

Figure 8 gives an overview of the procedures for the optimisation of cross-asset management, including the responsibilities of the parties to be affected.

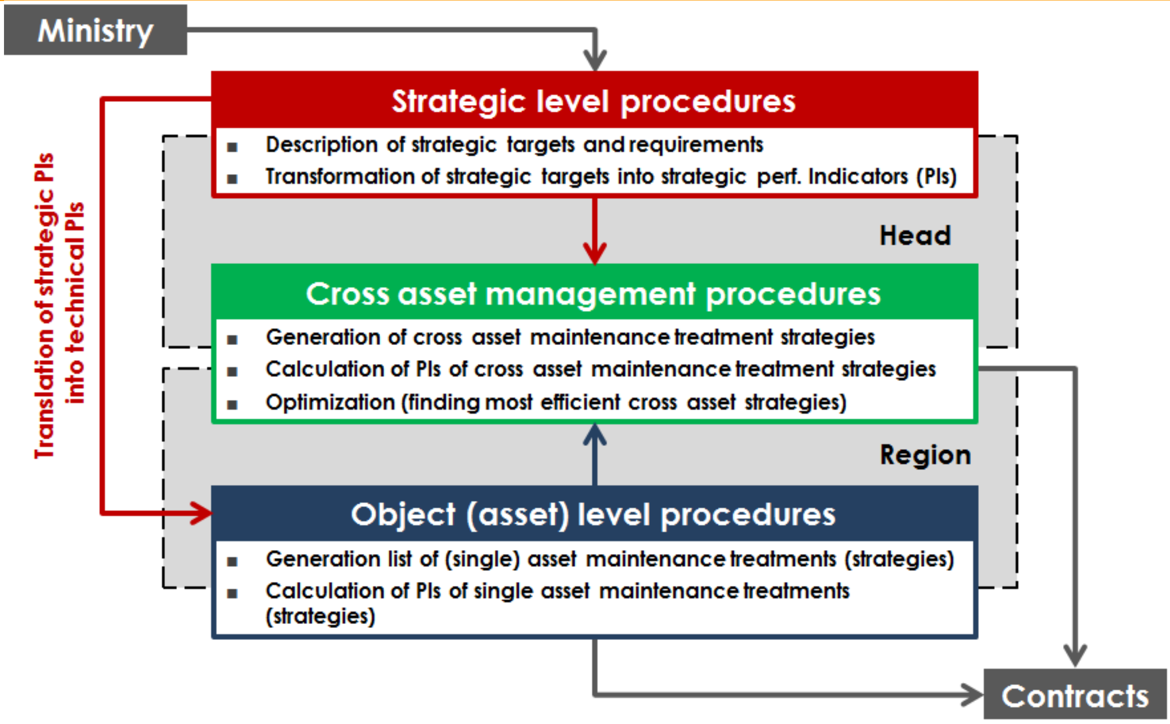


Figure 8: Cross-asset management procedures within the asset management approach

As already mentioned, the optimum solution should be the combination of coordinated maintenance activities, which achieve the targets best and/or minimize the difference between the targets and the actual possibilities taking into account the maintenance needs on object level. The optimisation combines both, the strategic level and the object level. Of course, the optimum solution as result of cross-asset management will not be the optimum solution neither on strategic level nor on object (technical) level. It will always be a compromise on the objectives to be taken into consideration. In general, the cross-asset optimisation comprises the following procedures:

- Description of strategic targets and agreements with ministry;
- Translation of strategic targets to (technical) performance indicators and parameters;
- Single asset specific maintenance treatments;
- Based on the list of (single) asset maintenance treatments, different combined maintenance treatment strategies (combination of different maintenance activities on different assets within a given time period) have to be defined (automated, semi-automated or manually);
- The strategic target-related PIs have to be calculated for cross-asset maintenance treatment strategies (coordinated maintenance programmes);
- Within the mathematical optimisation, the most efficient cross-asset maintenance strategy over the whole network should be found to meet strategic objectives (e.g. finding the most efficient cross-asset treatments with the lowest VOC under budgetary constraints).

The output of this process is a list of recommended maintenance treatments to achieve pre-defined strategic targets on the investigated network. This can be used a basis for developing coordinated short- to medium-term maintenance programmes.

In the following chapter, the different elements of cross-asset management procedures are explained in detail.

3.2 *Strategic targets and technical requirements*

One of the key factors for developing a holistic Asset Management approach are the different stakeholders' requirements, which are finally constituting the definition of strategic targets and technical and strategic performance indicators (PIs). In general, these road- or asset-specific requirements can be summarized into the following main targets (Deix, S., et al. (2012b)):

- Maximization of traffic safety
- Maximization of riding comfort
- Maximization of availability
- Minimization of negative environmental impacts and effects
- Compliance with maintenance budget restrictions
- Other strategic or political requirements and targets

The translation and relation between strategic targets and performance indicators is decisive for a meaningful cross-asset management process. Different relations between a technical parameter and a strategic target are found in practice:

a.) The same technical parameter is used on (technical) object level as well as on a strategic level (e.g. evenness).

b.) The performance indicator corresponding to a strategic target is used as well on the object level (e.g. condition indicator)

c.) A mathematical or functional relation between a technical parameter and a performance indicator reveals the relation between (technical) object level and strategic targets.

In order to avoid that strategic objectives are inferred from technical parameters which are not easily understood by all stakeholders or simplified performance indicators miss the range and diversity off recognised effects in asset management a clear translation from strategic targets to performance and measurement is required. Further, an indication how maintenance changes the performance is needed. Table 8 aids in understanding the relations between strategic targets, performance indicators and technical parameters.

Table 10: Connection of strategic requirements, performance indicators and technical parameters

Strategic requirements	**Performance Indicators**	**Technical Parameters**
Safety	Accident rate Fatalities	Rutting, Skid resistance, Texture, etc.
Costs (direct)	Costs	Costs, Structural condition, etc.
Availability	Vehicle lost hours	Specific availability parameters
Customer satisfaction	Results from customer satisfaction surveys	Specific survey parameters
Environment	CO2, Particle emissions Noise,	Rolling resistance, Texture, Evenness, Surface condition, Rolling noise emissions,
Target achievement	**Benefit**	**Treatment effect**
Service Level Agreement (SLA)	**Network construction programme**	**Maintenance treatment**

The translation of strategic targets into technical indicators is a key issue in the whole process. For the integration of the strategic goals into a technical process, the performance indicators (PIs) have to be described in the form of one or more (technical) performance indicators. For example, the safety and comfort requirements on the road pavement can be described by thresholds of rutting, skid resistance, roughness, etc. These parameters are usually based on national and international standards in comparison to other requirements (e.g. available maintenance budget, the availability, the environmental impact, etc.), which are strongly influenced by the economic, the environmental and finally the political situation.

3.3 Strategic and technical performance indicators

An essential precondition for the practical application of cross-asset management is the definition of adequate performance indicators (Deix, S., et al. (2012b)).Indicators for the description of the effects of treatments on single assets or of effects caused by coordinated maintenance planning are:

- Costs

- Benefit (effect of a maintenance on achieving the strategic targets)
- Combination of costs and benefit (e.g. cost-benefit ratio)

In addition the boundary conditions on the strategic and the object level have to be considered:

  - Budgetary restrictions
  - Strategic restrictions
  - Technical restrictions and minimum requirements
  - Others

Both, indicators and boundary conditions are based on different input parameters or calculated from single indicators into combined performance indicators. For the practical application of cross-asset management procedures these parameters need to be specified. Within PROCROSS the following parameters were defined:

- External costs (*ExC*)
- Benefit (*BE*)
- Construction costs (*CC*)
- Minimum technical requirements of an asset *a*, expressed by a technical parameter or an index (*minTPa*)

Based on this list the following parameters for the effects of a maintenance treatment strategy *M* of an asset *a* for a given time frame *t* were defined as:

- Present value construction costs of maintenance treatment strategy *M* ($CC_{M,a}$)
- Present value external costs (Sum of costs due to condition of asset *a* and due to maintenance treatments on asset *a*) of maintenance treatment strategy *M* ($ExC_{M,a}$)

In addition to the parameters listed above, it is necessary to include a decision variable *X*, which guarantees the compliance of a maintenance treatment strategy *M with* minimum (technical) requirements*:*

$$X(M_a) = 1 \quad \text{for } TP_a \geq \mathrm{minTP_a}$$

$$X(M_a) = 0 \quad \text{for } TP_a < \mathrm{minTP_a}$$

3.4 Cross-asset maintenance treatment strategies

3.4.1 Asset-specific maintenance treatment strategies (object level)

In the context of life cycle cost analysis (LCCA), the planned maintenance treatments for a specific road asset (pavement, bridge element, etc.) need to be assessed according to their positive and negative effects over a certain time or assessment period respectively (Kong, J.S. et al. (2003)). The assessment period of LCCA is strongly dependent on the type of the assets to be analysed. To enable an assessment of treatment sequences it will be necessary to extent this period as long as possible, taking into consideration the statistical spread of the predicted values. In many NRAs the engineering structures show the longest assessment period (e.g. 70 years), followed by pavements (e.g. 30 years) and finally by road furniture and equipment (e.g. 10 years).

Within LCCA the prediction of the performance (condition) is a decisive factor for finding the best year or interval for a maintenance treatment. If the condition reaches a certain level (trigger), different maintenance options can be applied where the short- and long-term effects are usually different. If the effect of a maintenance treatment is short-term only another maintenance treatment is possible within assessment period. Thus, maintenance treatment sequences or asset-specific maintenance treatment strategies are thought of, consisting of a single activity or of more than one activity within the assessment period. Figure 9 shows the deterioration of a single road asset and the different options to improve the condition by applying maintenance treatments. The time frame for the application of maintenance treatments is a part of the assessment period. It is essential for the development of different asset specific treatment strategies and enables the variation of cross-asset maintenance treatment strategies finally. In Figure 9 the time frame for treatments starts at the time when the performance curve enters the application area of the treatments (trigger) and ends theoretically when the “do-nothing” curve exceeds the worst possible condition. In practice, the treatment strategy i is the solution, which fulfils the minimum requirements (latest possible intervention, low cost treatment). For this strategy a second time frame starts in short-term (which is not marked in Figure 9 but can be seen in Figure 10) by entering of the performance curve into the application area. The number of time frames for treatments depends on the starting point of the performance curves, on the deterioration rate, on the effects of the single maintenance treatments and finally on the length of the assessment period, which is different for different type of assets.

Each single maintenance option defined as an object- or element-specific treatment sequence can be described by different values or indicators. They enable the engineer or decision-maker to select the “best” solution in coincidence with the strategic targets and requirements but also within the (minimum) technical demands.

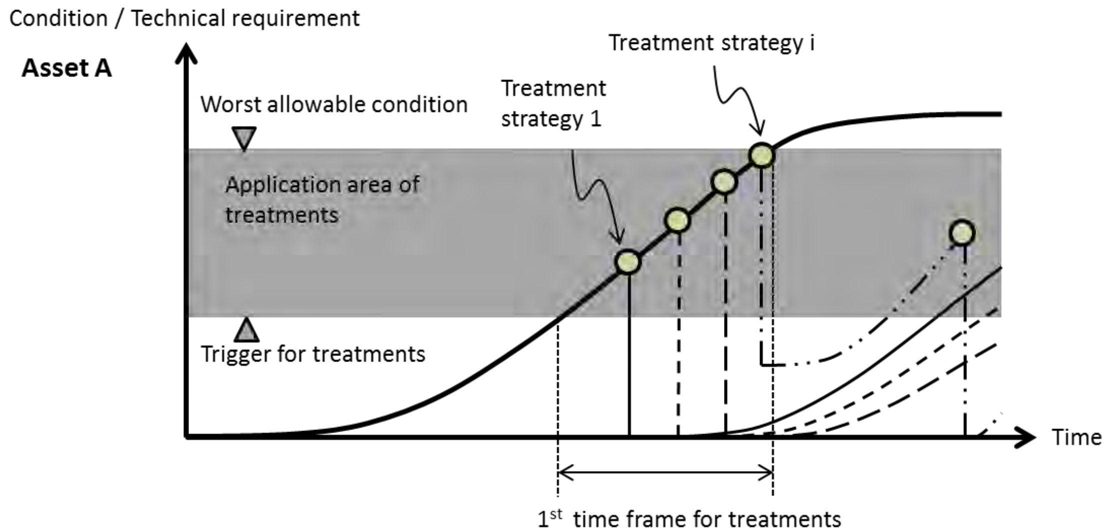


Figure 9: Deterioration and different maintenance treatment strategies of asset A

3.4.2 Maintenance projects

In many cases the coordination of asset-specific maintenance treatments is related to a larger maintenance project or scheme. It includes a certain number of assets, which are limited by a specific area and a certain time frame within the lifecycle. The coordination of asset-specific maintenance treatments will usually be carried out by the projects individually, but needs to be brought together over the whole network for the optimisation.

Based on the available information and the maintenance needs of the different single assets, it is possible to define such projects over the whole network for a given time frame. In many countries, the envisaged period for projects or schemes is between 1 and 6 years. It has to be stated that this period is different to the assessment or analysis period (in the context of LCCA) of single assets, which is usually much longer, especially for engineering structures and pavements.

For the definition of the projects or schemes the following parameters need to be taken into consideration:

- Year of construction of road
- Year of construction of assets along the road
- Condition and difference of condition between the different assets
- Performance prediction and maintenance intervals of assets
- Minimum and maximum length of construction sites
- Sequence and extent of assets
- Asset value
- Cross section of road
- Critical phase of assets
- Traffic routing
- Spatial situation
- Others

3.4.3 Generation of cross-asset maintenance treatment strategies

In order to reduce the negative effects of maintenance treatments, it is preferable to combine activities into larger maintenance projects. Thus, the main objective of cross-asset management is to fulfil the given strategic, economic and of course technical requirements with the lowest negative effects to the different stakeholders over the whole network and over all projects or schemes.

The task to combine treatments and measures can be quite complex and is strongly related to the number of assets or sub-assets involved. Further, the spatial distribution of maintenance needs on the different assets is a decisive factor. In many countries the combination of maintenance treatments from different assets is based on engineering insight, letting the asset managers and engineers assess and estimate consequences manually. The primary aim of cross-asset management is not to replace the engineering judgement, but to complement it with better information and indicators enabling the asset managers and engineers to assess different *Cross-asset Maintenance Treatment Strategies*. These indicators are described below. Furthermore, it is beneficial to use these indicators for finding solutions which best fulfil the different requirements. For this purpose, an optimisation routine can be used. This will also be described below.

Figure 10 shows schematically the combination of asset-specific maintenance treatment sequences or strategies (Asset A+B). The different *Cross-asset Maintenance Treatment Strategies* are based on the deterioration of the single assets. Figure 10 shows, that a possible *Cross-asset Maintenance Treatment Strategy* (e.g. Cross-asset Maintenance Treatment Strategy 2) is only the sequence of individual single treatments of asset A and B. They do not offer a combined treatment potential. Cross-asset Maintenance Treatment

Strategies 1 is a real combination of maintenance activities on asset A and B.

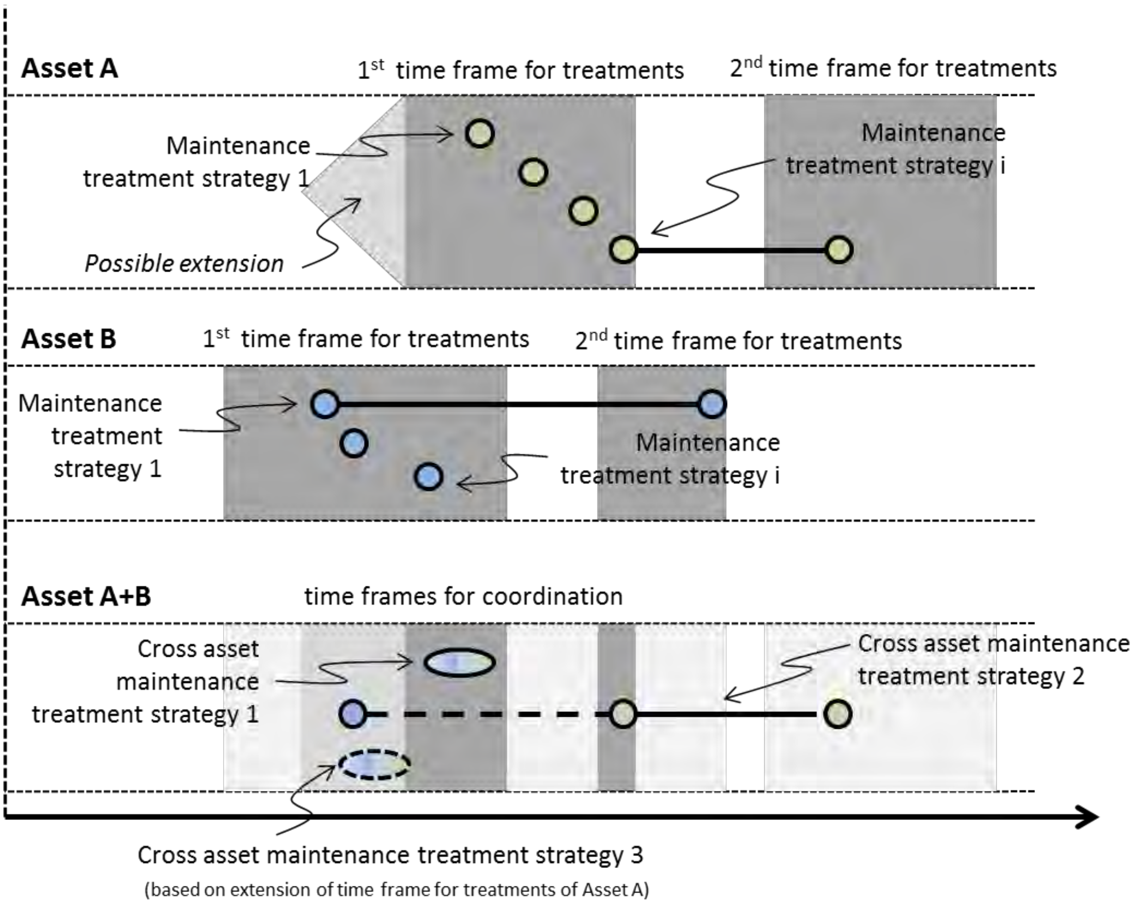


Figure 10: Combination of asset-specific treatment strategies to cross-asset maintenance treatment strategies

Independent from the main target, to combine the asset-specific treatments as far as possible, it will be necessary to keep the 'uncombined' solutions in the procedure. Otherwise it will be not possible to fulfil all given requirements. Sometimes, it makes sense to extend the time frame for finding more combination possibilities.

As a result of this discussion the following main groups of *Cross-asset Maintenance Treatment Strategies* can be defined:

- *Cross-asset Maintenance Treatment Strategies*, which are based on a real combination of single asset specific maintenance treatments (e.g. Cross-asset Maintenance Treatment Strategy 1)
- *Cross-asset Maintenance Treatment Strategies*, which are based on a sequence of single uncombined maintenance treatments of single assets (e.g. Cross-asset Maintenance Treatment Strategy 2)
- *Cross-asset Maintenance Treatment Strategies*, which are based on an extension of the application area to combine asset specific maintenance treatments (e.g. Cross-asset Maintenance Treatment Strategy 3)
- Combination of the previous *Cross-asset Treatment Strategies*

Within cross-asset management, it is necessary to distinguish between the different groups because the performance indicator calculation describing the *Cross-asset Maintenance Treatment Strategies* can be different. Cross-asset maintenance treatment strategies CM_p of a project p not fulfilling the minimum (technical) requirements $X(M_a) = 0$ have to be excluded from the combination process.

3.4.4 Indicators of cross-asset maintenance treatment strategies

Indicators for the description of cross-asset maintenance treatment strategies are needed to calculate the costs, the (positive) effects and finally the benefit of the different solutions. Based on these indicators it should be possible to select those cross-asset maintenance treatment strategies, which enable to achieve the strategic targets best and/or to minimize the difference between the targets and the actual possibilities from different point of views (economic, user, environmental, technical, etc.). The main problem to be solved is the summation or aggregation of effects over different assets. For instance, the positive effect of the replacement of an inefficient noise barrier will be described with different indicators in comparison to the replacement of a pavement surface layer, which reduces rutting and increases the safety of the road. For the assessment of cross-asset maintenance treatments strategies the different effects need to be summarized or aggregated, otherwise it will not be possible to define an overall benefit, which is a main indicator of the asset management framework and a basis for the target achievement.

The selection of the following indicators of cross-asset maintenance treatment strategies is based on the intensive discussion within the TAB and the experience of the project team. The described solution provides an applicable basis, which can be easily adapted to different framework conditions. The indicators to describe *Cross-asset Maintenance Treatment Strategies* can be grouped in the same way as the indicators of asset-specific maintenance treatment sequences or strategies on object level. *Cross-asset Maintenance Treatment Strategy* can be described by the following indicators (OptiMAL (2012)):

- **Present value construction costs** of coordinated cross-asset maintenance treatment strategy CM_p of a maintenance project p in year t, taking into account different assets a ($CC_{CM,p,t}$)
  - for combined maintenance treatments

$$CC_{CM,p,t} = \bigcup_{A} CC_{M,a,p,t} \quad \text{for all } X(M_a) = 1$$

  - for maintenance treatment sequences (uncombined)

$$CC_{CM,p,t} = \sum_{A} CC_{M,a,p,t} \quad \text{for all } X(M_a) = 1$$

- **Present value construction costs** of coordinated cross-asset maintenance treatment strategy CM_p of a maintenance project p over the whole assessment period, taking into account different assets a ($CC_{CM,p}$)
  - for combined maintenance treatments

$$CC_{CM,p} = \sum_{t} \bigcup_{A} CC_{M,a,p,t} \quad \text{for all } X(M_a) = 1$$

  - for maintenance treatment sequences (uncombined)

$$CC_{CM,p} = \sum_{t} \sum_{A} CC_{M,a,p,t} \quad \text{for all } X(M_a) = 1$$

- **Present value external costs** of coordinated cross-asset maintenance treatment strategy CM_p of a maintenance project p over the whole assessment period, taking into account different assets a ($ExC_{CM,p}$)
  - for combined maintenance treatments

$$ExC_{CM,p} = \bigcup_{A} ExC_{M,a,p} \quad \text{for all } X(M_a) = 1$$

  - for maintenance treatment sequences (uncombined)

$$ExC_{CM,p} = \sum_{A} ExC_{M,a,p} \quad \text{for all } X(M_a) = 1$$

  The use of external costs enables an applicable (back) translation of technical effects of maintenance treatments into monetary terms and an easy summation or aggregation over all assets for the definition of the benefit (see below). Furthermore, a high number of models and calculation procedures are existing and available for different types of treatments. Theoretically, the external costs can be replaced by non-monetary indicators, where the asset-specific effects have to be weighted according to the extent of target achievement before summation or aggregation over all assets. The definition of such weights could be quite complex and needs a clear understanding of the different importance or meaning of different objectives and targets (e.g. priority of safety in comparison to environment, priority of comfort in comparison to sustainability, etc.).

- **Potential of coordination**

  An additional indicator of coordinated cross-asset maintenance planning is the potential cost-saving through coordinated maintenance activities. The more maintenance treatments of different assets are combined at the same time, the better the coordination is. Although the external costs indicate the effect indirectly, the calculated values do not always show the positive effect in such extent. In particular the effect of coordinated maintenance treatments with very low savings on external costs (e.g. bridge maintenancetreatment, which does not affect the road users) needs to be higher valuated by referring to this added value through coordination ($PC_{CM,p}$). The potential of coordination $PC_{CM,p}$ of a coordinated cross-asset maintenance treatment strategy CM_p of a maintenance project p, over the whole assessment period, taking into account different assets a, can be defined over the number of coordinated asset specific maintenance treatments C as follows:

$$PC_{CM,p} = \sum_{C} CM_{a,p}$$

- **Benefit of a coordinated cross-asset maintenance treatment strategy**

  Beside costs, the benefit is the second essential indicator for the assessment of coordinated cross-asset maintenance treatment strategies. The benefit can be defined as the sum or aggregation of all positive impacts of maintenance treatments towards achieving strategic targets of the respective asset. Theoretically, the cross-asset maintenance treatment benefit is the sum or aggregation of all effects caused by single, asset-specific maintenance activities, which are defined within the cross-asset maintenance treatment strategies. The effects can be derived by the treatment specific “reset-values” for the different technical parameters. As already described in chapter 2.3 the benefit will be usually calculated as a relative value in the form of a comparison between the “do-nothing” solution or the maintenance activities to be carried out to fulfil the minimum requirements and the respective cross-asset maintenance treatment strategy.

For the benefit calculation of cross asset maintenance treatment strategies the technical effects have to be (back) translated into the consequences subject to the strategic targets (see Figure 11). As already mentioned, external costs are an applicable solution to solve the problem of the summation or aggregation of different (technical) effects over different assets of a project *p*.The benefit $BE_{CM,p}$ of a coordinated cross-asset maintenance treatment strategy CM_p of a maintenance project *p,* over the whole assessment period, taking into account different assets *a,* in relation to the maintenance treatment strategy, which fulfils the minimum (technical) requirements ($minCM_p$), can be defined by using the external costs (*ExC*) as follows:

$$BE_{CM,p} = ExC_{\min CM,p} - ExC_{CM,p}$$

$$BE_{\mathrm{min}CM,p} = ExC_{do-noting,p} - ExC_{\mathrm{min}CM,p}$$

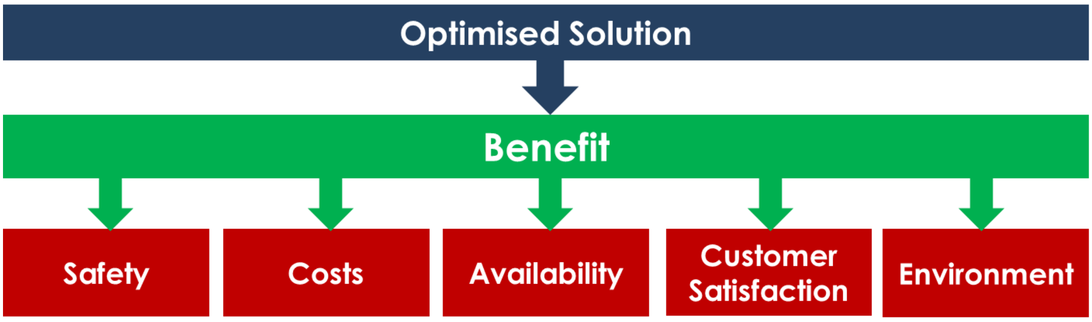


Figure 11: Attribution of the benefit of optimised solution to stakeholder objectives.

- **Efficiency and benefit-cost ratio**

To include only those solutions in the optimisation process which offer a good economic solution, it is necessary to asses each coordinated cross-asset maintenance treatment strategy according to its efficiency. The most effective way of assessment is the comparison of costs and benefits in the form of a benefit-cost ratio. In order to include the strategy which fulfils the minimum (technical) requirements (which could be an uneconomic solution), it is necessary to calculate the cost-benefit ratio in relation to this strategy.

The benefit-cost ratio $BCR_{CM,p}$ of a coordinated cross-asset maintenance treatment strategy CM_p of a maintenance project *p* in relation to the maintenance treatment strategy, which fulfils the minimum (technical) requirements ($minCM_p$), can be defined by using the construction costs (*CC*) and the benefit (*BE*) as follows:

$$BCR_{CM,p} = \frac{BE_{CM,p} - BE_{\mathrm{min}CM,p}}{CC_{CM,p} - CC_{\mathrm{min}CM,p}}$$

For strategies, which show a negative difference to the benefit and/or costs BCR, should be set to zero.

3.4.5 Optimisation Approach

In order to find an optimal solution it is necessary to identify the combination of *Cross-asset Maintenance Treatment Strategy* CM_p over the whole network (sum of projects *p*) best contributing to fulfilling the strategic targets. For this purpose, different optimisation targets can be defined, taking into account all, or only the most relevant indicators.

As already described, the optimum solution are those cross-asset management treatment strategies of a road infrastructure network, which achieve the strategic targets best, taking into consideration the maintenance needs of the single asset on object or technical level. Of course, this definition leads to a quite complex optimisation problem, because the optimisation has to be carried out over the whole network and over a certain time period by using a high number of indicators or parameters respectively. Theoretically, a multi-criteria optimisation has to be defined, which can be mathematically or computationally difficult to be included practically. Although the number of parameters could be reduced to a minimum, the solution of the optimisation problem needs to use special mathematical software tools and significant mathematical experience and expertise in optimisation. Commercial asset management tools usually do not offer such mathematical units and a practical solution should be simplified as much as possible without compromising with the cross-asset management philosophy discussed in this report. Furthermore, a real mathematical solution by using multi criteria optimisation would cause a long processing period and does not necessarily guarantee a better solution than a simplified comprehensible approximation. It has to be stated at this point, that PROCROSS focuses on the framework and on influencing parameters and good practice examples but not on improving the mathematical optimisation algorithm. Nevertheless, the following optimisation approach will offer a solution, which reduces the complex optimisation problem into single target optimisation, where on the one hand most of the influencing factors are brought together (summarized or aggregated) in form of combined performance indicators and on the other hand defined as compliances and constraints. This solution is applicable for non-mathematicians and could be incorporated into existing (commercial) asset management tools under justifiable efforts.

The following general definition of the optimisation target is based on maximizing the benefit of all *Cross-asset Maintenance Treatment Strategies* over the whole network considering only those strategies fulfilling the economic and technical requirements as well as budgetary and other constraints (OptiMAL (2012)).

Mathematically, the optimisation objective can be described by a target function T, which is equal to the total benefit BE_{total} of all projects *p*:

$$T = BE_{total} = \sum_{P} \sum_{CM} ExC_{CM,p} \cdot PC_{CM,p} \cdot Y_{CM,p} \Rightarrow \text{max!}$$

The following constraints have to be met:

- Compliance that two or more maintenance treatment strategies of a project *p* will not be selected at the same time by using the decision variable *Y*:

$$\sum_{CM} Y_{CM,p} \leq 1 \quad \text{for} \quad p = 1,\ldots,n$$

- Compliance that the yearly available maintenance Budget Bud_t will not be exceeded by the construction costs of the maintenance treatments in a certain year:

$$\sum_{P} CC_{CM,p,t} \cdot Y_{CM,p} \leq Bud_t \quad \text{for} \quad t = 1,\ldots,n$$

- Compliance that the yearly available budget Bud_t is greater than the minimum budget minBud_t to fulfil the minimum (technical) requirements:

$$Bud_t \geq \min Bud_t \quad \text{for} \quad t = 1, \ldots, n$$

- Compliance that the efficiency of the maintenance treatment strategy is higher than the minimum efficiency $minBCR_{CM,p}$:

$$BCR_{CM,p} \geq \min BCR_{CM,p} \quad \text{for} \quad p = 1, \ldots, n \quad \text{for} \quad CM = 1, \ldots, n$$

The sum over all projects in the target function converts the project *p* related problem into a net-wide optimisation under the given constraints. The output of the optimisation will be a list of cross-asset management treatment strategies (consisting of single asset specific maintenance treatments) of all projects *p* of a road infrastructure road network. The following example should help to understand the described approach.

3.5 Example of cross-asset management optimisation

3.5.1 Network overview and input

The following generic example should give an overview of the solution described above and help the reader of this report to understand the basic ideas of PROCROSS.

As shown in Figure 12, the network consists of a limited number of roads (Road A to G), which are subdivided into 3 projects (A, B and C). Each project (scheme) includes different assets (pavement P, bridge B, tunnel T, noise barrier N).

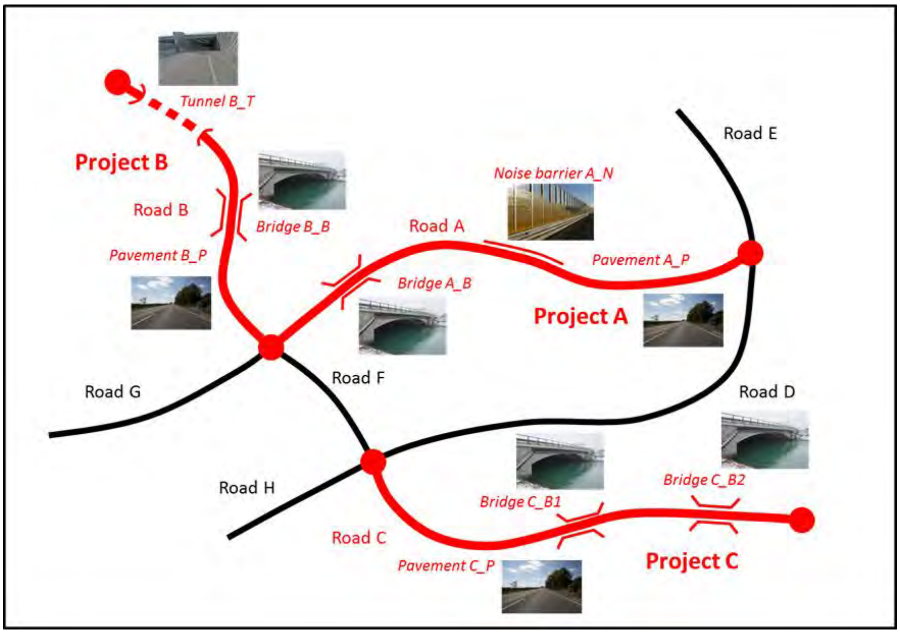


Figure 12: Example – network, projects and assets

The main objective of the cross-asset optimisation is to find a solution of maintenance activities, which maximizes the benefit under given requirements (technical and strategic ones). The following list shows these requirements and targets in detail:

- Compliance with minimum technical requirements

- Maintenance activities should cause the lowest possible user disturbance
- Application of high efficient and sustainable maintenance treatment strategies
- In the year 2016, on parallel Road D extension works from 2 to 4 lanes (fixed measure!)
- Maintenance activities within budgetary constraints
- Cross-asset optimisation period: 2013 to 2017 (period of construction programme)

The yearly budgetary constraints can be taken from Figure 13, which shows two possible budget scenarios for the whole optimisation period.

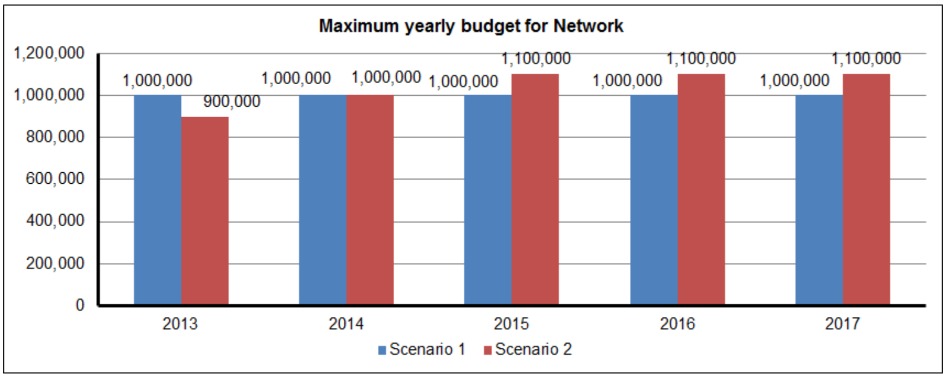


Figure 13: Example – yearly budgetary constraints

3.5.2 Calculation steps

The first step of the approach is to define and assess the maintenance needs of each single asset for the 3 different projects. The assessment is based either on a sophisticated management system (PMS) or on simple engineering judgement. Regardless of the method (e.g. LCCA) and the assessment period for the different assets - which is usually much longer than the cross-asset management period - a list of possible asset-specific maintenance treatments is the output. The following Figure 14 shows outputs of the asset-specific analysis (maintenance treatment strategy list) for the pavements of project A. The calculation of costs, disturbance and savings (= performance indicators) are based on local models and will not be explained in detail here.

Technical assessment of pavement
Output of PMS-analysis

Treatment Strategy	Treatment	Year	Cost	Disturbance	Savings	Do Minimum?
A_P1	PATCH	2015	6,000	2,500	300	
	PATCH	2017	6,000	2,500	200	
			12,000	**5,000**	**500**	Yes
A_P2	OVL	2015	800,000	20,000	64,000	
			800,000	**20,000**	**64,000**	No
A_P3	PATCH	2015	6,000	2,500	300	
	OVL	2016	800,000	20,000	59,000	
			806,000	**22,500**	**59,300**	No
A_P4	PATCH	2015	6,000	2,500	300	
	OVL	2017	800,000	20,000	64,000	
			806,000	**22,500**	**64,300**	No
A_P5	PATCH	2015	6,000	2,500	300	
	PATCH	2017	6,000	2,500	200	
	OVL	2017	800,000	20,000	64,000	
			812,000	**25,000**	**64,500**	No
A_P6	PATCH	2015	6,000	2,500	300	
	REINF	2017	2,100,000	120,000	211,400	
			2,106,000	**122,500**	**211,700**	No

Figure 14: Example – output of asset-specific analysis (maintenance treatment strategy list) for the pavements of project A

If an asset-specific maintenance treatment strategy does not fulfil the minimum technical requirements or is in conflict with other preconditions (e.g. 2016 on parallel road D extension works), the solution will be excluded (e.g. A_P3, A_P5, red light on the right). Furthermore, the strategy, which fulfils the minimum requirements with the lowest effort, is defined in the "Do-Minimum?" column.

The same procedure can be carried out with all the other assets in the projects. Figure 15 shows the output of this process for the tunnel B_T of project B.

Technical assessment of tunnel
Asessment in the context of tunnel-safety program

Treatment Strategy	Treatment	Year	Cost	Disturbance	Savings	Do Minimum?
B_T1	IMPR E+M	2013	890,000	17,400	61,000	
			890,000	**17,400**	**61,000**	No
B_T2	IMPR E+M	2014	890,000	17,900	59,000	
			890,000	**17,900**	**59,000**	Yes

Figure 15: Example – output of asset-specific analysis (maintenance treatment strategy list) for the tunnel of project B

The next step in the procedure is the generation of cross-asset maintenance treatment strategies in the form of a combination of possible asset-specific solutions. This was carried out manually and yielded a high number of solutions for each single project. Figure 16 shows the list of cross-asset maintenance treatment strategies of project B, which consists just of the tunnel B_T and the bridge B_B. The pavement of project B is in good condition and does not need maintenance at the given time. The last strategy B_C6 (T1+B"New") was defined by an extension of the maintenance application area of the bridge, where the BMS does not offer this asset-specific solution

Cross asset treatment strategies
Combination of asset specific treatment strategies or sequences


Treatment Strategy	Treatment	Year	Cost	Disturbance	Savings	Do Minimum?
B_C1	IMPR E+M	2014	890,000	17,900	59,000	
T2			**890,000**	**17,900**	**59,000**	Yes
B_C2	IMPR E+M	2013	890,000	17,400	61,000	
T1			**890,000**	**17,400**	**61,000**	No
B_C3	IMPR E+M	2013	890,000	17,400	61,000	
T1+B1	MAINT SUPSTR	2017	22,000	600	4,000	
			912,000	**18,000**	**65,000**	No
B_C4	IMPR E+M	2014	890,000	17,900	59,000	
T2+B1	MAINT SUPSTR	2017	22,000	600	4,000	
			912,000	**18,500**	**63,000**	No
B_C5	IMPR E+M	2014	890,000	17,900	59,000	
T2+B"New"	MAINT SUPSTR	2014	18,000	0	4,000	
			908,000	**17,900**	**63,000**	No
B_C6	IMPR E+M	2013	890,000	17,400	61,000	
T1+B"New"	MAINT SUPSTR	2013	17,000	0	4,000	
			907,000	**17,400**	**65,000**	No

Figure 16: Example – generation of cross-asset maintenance treatment strategies of project B

Based on this list, the cross-asset maintenance treatment strategies can be compared to each other (in relation to Do-Minimum-strategy) and ranked according to their benefit-cost ratio as shown in Figure 17.The costs in the table are the total costs for this strategy for the given period. The green light on the right shows that all the strategies could be used for the network optimisation.

Comparison of cross asset treatment strategies
Comparison based on cost-benefit-ratio calculation (in relation to Do-Minimum-strategy = starting point)

Treatment Strategy	Costs	Benefit	Do Minimum?	ΔCost to Min.	ΔBenefit to Min.	BC-ratio
B_C1	890,000	41,100	Yes	0	0	0.000
B_C2	890,000	43,600		0	2,500	1.000
B_C3	912,000	47,000		22,000	5,900	0.268
B_C4	912,000	44,500		22,000	3,400	0.155
B_C5	908,000	45,100		18,000	4,000	0.222
B_C6	907,000	47,600		17,000	6,500	0.382

Figure 17: Example – comparison of cross-asset treatment strategies of project B

A similar list is shown in Figure 18 for project A, where some of the cross-asset maintenance treatment strategies have to be excluded because of a negative benefit-cost ratio (A_C2 and A_C3) or because of an exceeding of the yearly available budget of both scenarios (A_C13 to A_C16).

Comparison of cross asset treatment strategies

Comparison based on cost-benefit-ratio calculation (in relation to Do-Minimum-strategy = starting point)

Treatment Strategy	Costs	Benefit	Do Minimum?	ΔCost to Min.	ΔBenefit to Min.	BC-ratio
A_C1	57,000	-23,600	Yes	0	0	0.000
A_C2	57,000	-25,500		0	-1,900	0.000
A_C3	57,000	-25,700		0	-2,100	0.000
A_C4	225,000	-19,800		168,000	3,800	0.023
A_C5	844,900	23,000		787,900	46,600	0.059
A_C6	792,900	42,800		735,900	66,400	0.090
A_C7	844,900	22,400		787,900	46,000	0.058
A_C8	1,012,900	26,200		955,900	49,800	0.052
A_C9	850,900	20,800		793,900	44,400	0.056
A_C10	851,000	23,100		794,000	46,700	0.059
A_C11	799,000	42,700		742,000	66,300	0.089
A_C12	962,000	46,500		905,000	70,100	0.077
A_C13	2,151,000	68,200		2,094,000	91,800	0.044
A_C14	2,151,000	68,000		2,094,000	91,600	0.044
A_C15	2,049,000	92,600		1,992,000	116,200	0.058
A_C16	2,212,000	96,400		2,155,000	120,000	0.056
A_C17	792,900	45,000		735,900	68,600	0.093

Figure 18: Example – comparison of cross-asset treatment strategies of project A

In the next step, the remaining cross-asset maintenance treatment strategies have to be brought together and optimised under the given restrictions. The benefit-cost ratio is the decisive factor for the selection of the most adequate solution in this example (see Figure 19). To include the importance of the road, a weighting factor was implemented and used to weight the benefit-cost ratio.

Based on this list, the selection of the most adequate (optimised) solution was done by an iterative process, where the highest benefit-cost ratio should be achieved under the budgetary constraints.

Cross asset optimization over whole network

Comparison based on cost-benefit-ratio and benefit calculation

Treatment Strategy	ΔCost to Min.	ΔBenefit to Min.	Do Minimum?	BC-ratio	Weight	BC-ratio
C_C2	0	3,500		1.000	1.2	1.200
B_C2	0	2,500		1.000	1.1	1.100
B_C6	17,000	6,500		0.382	1.1	0.421
C_C7	316,000	101,250		0.320	1.2	0.384
C_C8	316,000	97,750		0.309	1.2	0.371
B_C3	22,000	5,900		0.268	1.1	0.295
C_C5	274,000	62,250		0.227	1.2	0.273
C_C6	274,000	58,750		0.214	1.2	0.257
B_C5	18,000	4,000		0.222	1.1	0.244
B_C4	22,000	3,400		0.155	1.1	0.170
A_C17	735,900	68,600		0.093	1.0	0.093
A_C6	735,900	66,400		0.090	1.0	0.090
A_C11	742,000	66,300		0.089	1.0	0.089
C_C3	54,000	3,750		0.069	1.2	0.083
A_C12	905,000	70,100		0.077	1.0	0.077
A_C5	787,900	46,600		0.059	1.0	0.059
A_C10	794,000	46,700		0.059	1.0	0.059
A_C7	787,900	46,000		0.058	1.0	0.058
A_C9	793,900	44,400		0.056	1.0	0.056
A_C8	955,900	49,800		0.052	1.0	0.052
A_C4	168,000	3,800		0.023	1.0	0.023
A_C1	0	0	Yes	0.000	1.0	0.000
B_C1	0	0	Yes	0.000	1.1	0.000
C_C1	0	0	Yes	0.000	1.2	0.000

Figure 19: Example – total list of cross-asset treatment strategies of all projects

3.5.3 Results

The first output of the analysis is the solution which fulfils the minimum requirements, as can be seen in Figure 20.

Budget to reach minimum requirements

Treatment Strategy	Treatment	Year	Cost	Disturbance	Savings	Do Minimum?
A_C1	PATCH	2015	6,000	2,500	300	
P1+B4+N1	PATCH	2017	6,000	0	200	
	EXPJOINT	2017	40,000	25,000	3,400	
	MAINT	2015	5,000	0	0	
			57,000	**27,500**	**3,900**	Yes
B_C1	IMPR E+M	2014	890,000	17,900	59,000	
T2			**890,000**	**17,900**	**59,000**	Yes
C_C1	PATCH	2016	13,000	3,200	400	
P1+B2	PATCH	2017	14,000	3,250	500	
	REPLBEARING 1	2014	90,000	19,500	38,000	
			117,000	**25,950**	**38,900**	Yes

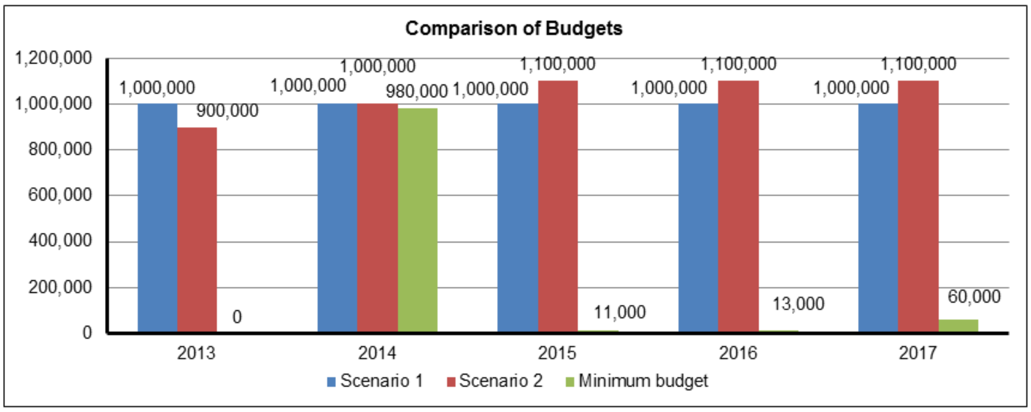


Figure 20: Example – solution which fulfils the minimum requirements

For the application of the asset-specific treatments, a minimum budget of 980 000 units in 2014, 11 000 units in 2015, 13 000 units in 2016 and 60 000 units in 2017 is needed. From an economic point of view, this solution offers the lowest benefit-cost ratio.

Because of the higher available budget, it is necessary to find solutions with a higher efficiency as can be seen in Figure 21 for scenario 1.

Optimal Solution Scenario 1

Treatment Strategy	Treatment	Year	Cost	Disturbance	Savings	Do Minimum?
A_C17	OVL	2014	750,000	0	66,000	
P"New"+B1+N"New"	EXPJOINT	2014	38,000	25,000	4,000	
	MAINT	2014	4,900	0	0	
			792,900	**25,000**	**70,000**	No
B_C6	IMPR E+M	2013	890,000	17,400	61,000	
T1+B"New"	MAINT SUPSTR	2013	17,000	0	4,000	
			907,000	**17,400**	**65,000**	No
C_C7	PATCH	2016	13,000	3,200	400	
P2+B3	SURFDRESS	2017	280,000	48,000	104,000	
	REPLBEARING 1	2013	90,000	19,000	41,000	
	EXPJOINT 2	2017	50,000	0	39,000	
			433,000	**70,200**	**184,400**	No

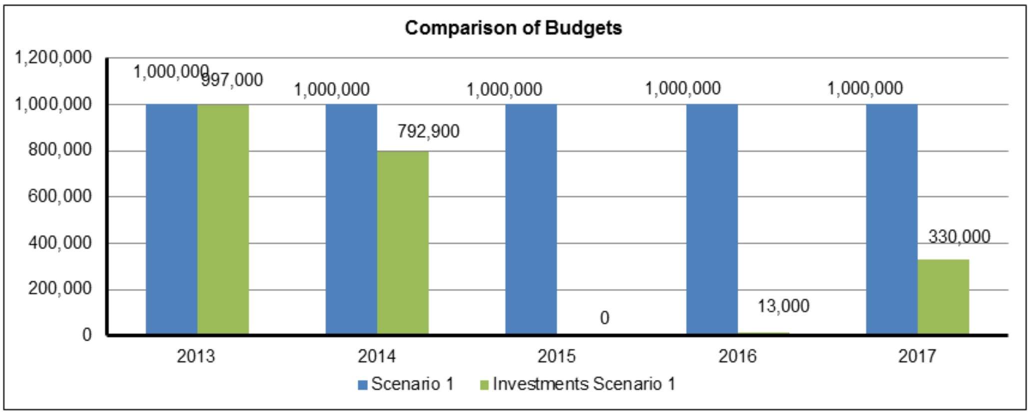


Figure 21: Example – solution scenario 1

Of course, the yearly investments of this scenario are much higher because of the higher intensity of the asset-specific maintenance treatments. The total investments are more than 2.1mil in comparison to the previous solution, which uses 1.064mil (sum of green columns in Figure 20) to fulfil the maintenance needs. The benefit-cost ratio for all selected treatment strategies of scenario 1 is greater than 0 (see Figure 19).

Figure 22 shows the results for scenario 2. Because of the lower budget in the first year, the asset-specific maintenance activities will be postponed mainly to 2014 and 2015 in comparison to scenario 1, where a high number of maintenance treatments will be applied already in 2013.

Optimal Solution Scenario 2

Treatment Strategy	Treatment	Year	Cost	Disturbance	Savings	Do Minimum?
A_C6	OVL	2015	750,000	0	64,000	
P2+B2+N1	EXPJOINT	2015	38,000	25,000	3,800	
	MAINT	2015	4,900	0	0	
			792,900	**25,000**	**67,800**	No
B_C5	IMPR E+M	2014	890,000	17,900	59,000	
T2+B"New"	MAINT SUPSTR	2014	18,000	0	4,000	
			908,000	**17,900**	**63,000**	No
C_C7	PATCH	2016	13,000	3,200	400	
P2+B3	SURFDRESS	2017	280,000	48,000	104,000	
	REPLBEARING 1	2013	90,000	19,000	41,000	
	EXPJOINT 2	2017	50,000	0	39,000	
			433,000	**70,200**	**184,400**	No

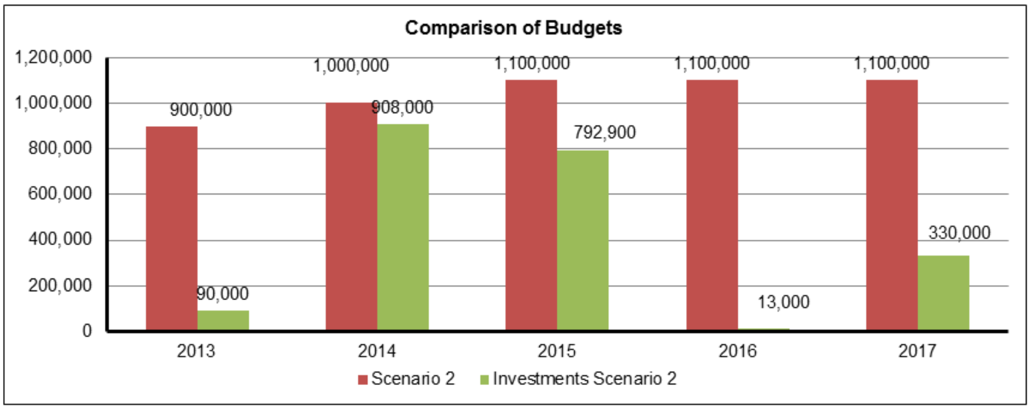


Figure 22: Example – solution scenario 2

4 Implementation

4.1 Overview of implementation process

As described in the previous chapters, cross-asset management procedures for improving the efficiency of maintenance treatments and achieving strategic targets is a useful approach. Besides the definition of different requirements of cross-asset management optimisation, the implementation process is connected with a high number of activities strongly dependent on the actual situation.

Thus, it is necessary to follow a pre-defined implementation process, which will be described in the following chapters at a glance. The main steps for the implementation are defined as follows:

- Analysis of current asset management situation and processes
- Definition of targets and objectives for the use of cross-asset management
- Implementation of new procedures and adjustment / extension of existing procedures
- Control and review

The following flow chart (Figure 23) gives an overview of the main implementation steps of cross-asset management procedures. In particular the control and review element is essential for the continuous improvement of the process and forms a causal loop-based solution.

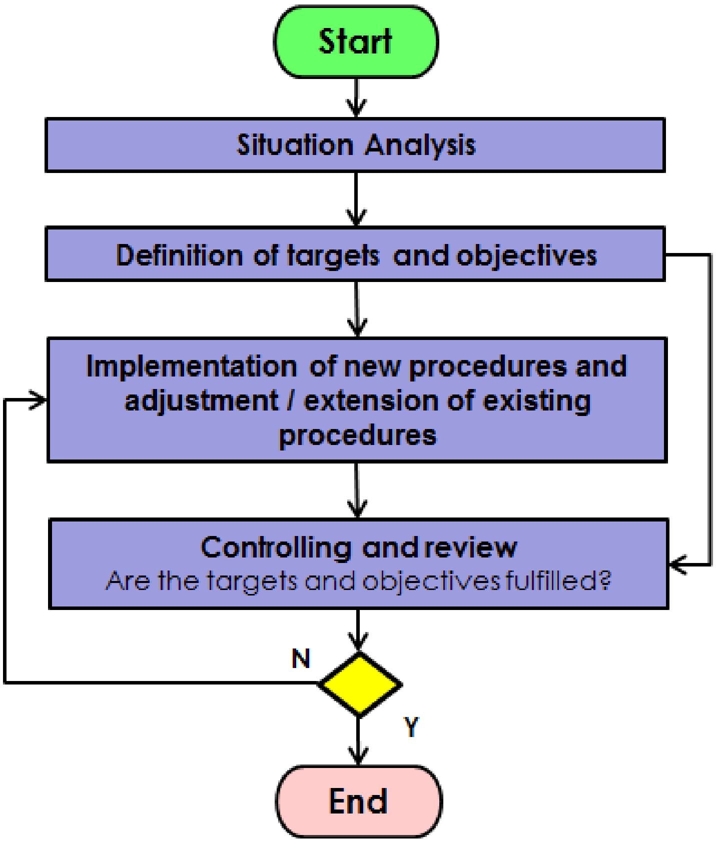


Figure 23: Main implementation steps

4.2 Analysis of current asset management situation and processes

Before the implementation of cross-asset management procedures should start, a detailed analysis of the current situation of the asset management processes is strongly recommended. It should provide a comprehensive basis for the implementation of new procedures or for the adaption of existing ones, as well as for the objectives and targets of the whole process. The situation analysis should focus on detailed questions describing the cross-asset management process, the organisational structure of the NRA, the definition of strategic and technical targets, responsibilities, etc. The following questions give an overview of the tasks to be covered within this analysis:

- How is the NRA organised and which elements of the organisation are involved in the cross-asset management process?
- Who is responsible for the different sub-processes and the different assets?
- Who defines strategic targets and how are they implemented and used in the current process?
- Which cross-asset management procedures exist and how are they used within the NRA?
- What data will be collected and how are they used on the technical level?
- What is the maintenance planning horizon for a NRA?

The systematic analysis of the existing cross-asset management situation can be sub-divided into 3 main areas:

- Situation analysis of the organisational structure of the NRA
- Situation analysis of target definitions and requirements
- Analysis of (single) assets and cross-asset management procedures

The following flow charts (Figure 24 to Figure 26) and the corresponding assessment matrix (Table 11) should help the user to carry out the situation analysis and to find out which current cross-asset management approach is applied in the NRA. Each flow chart contains different questions, which should be answered and lead to a number, which could be used in the corresponding assessment matrix (Table 11). It is recommended that the flow charts will be used by a team of experienced asset managers or by more than one asset manager individually. The flow charts should provide a basis for discussion, because not all of the questions could be easily answered with yes or no. Of course, it has to be stated that the different flow charts must be seen as a general basis for the analysis and should be extended or adapted to the local requirements and preconditions.

The first flow chart (Figure 24) can be used to describe the organisational structure of the NRA. It includes questions about the location of cross-asset management procedures within the NRA, as well as the location of the analysis of the different single assets.

The second chart (Figure 25) enables the assessment of the definition of strategic targets and requirements and their translation (transformation) into (technical) performance indicators. Furthermore, it includes the question about the use of the strategic targets in the analysis process of the different (single) assets.

The third flow chart (Figure 26) focuses on the assessment of existing cross-asset management procedures and asset-specific measures according to given strategic requirements.

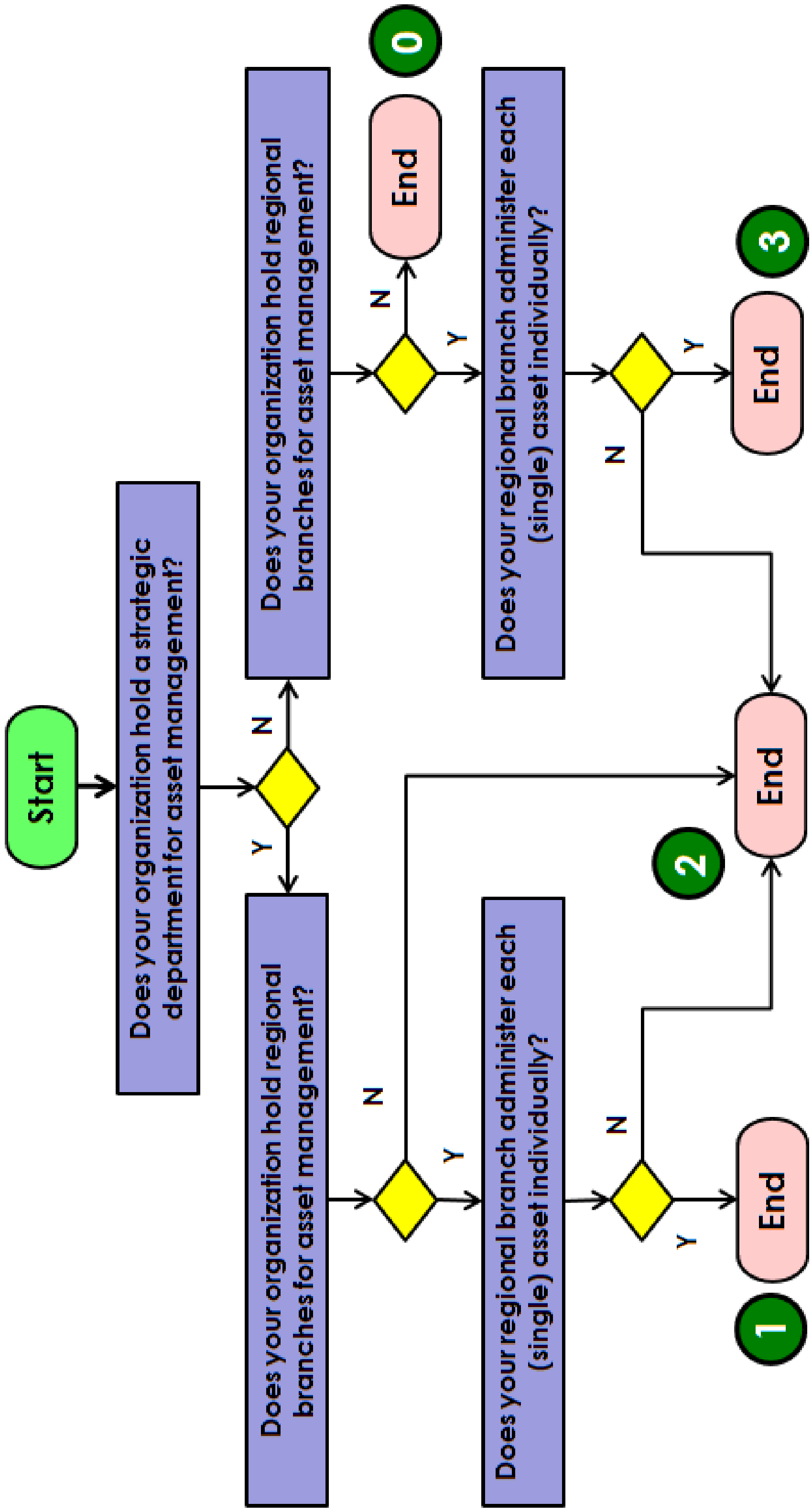


Figure 24: Flow chart for the situation analysis of the organisational structure of the NRA

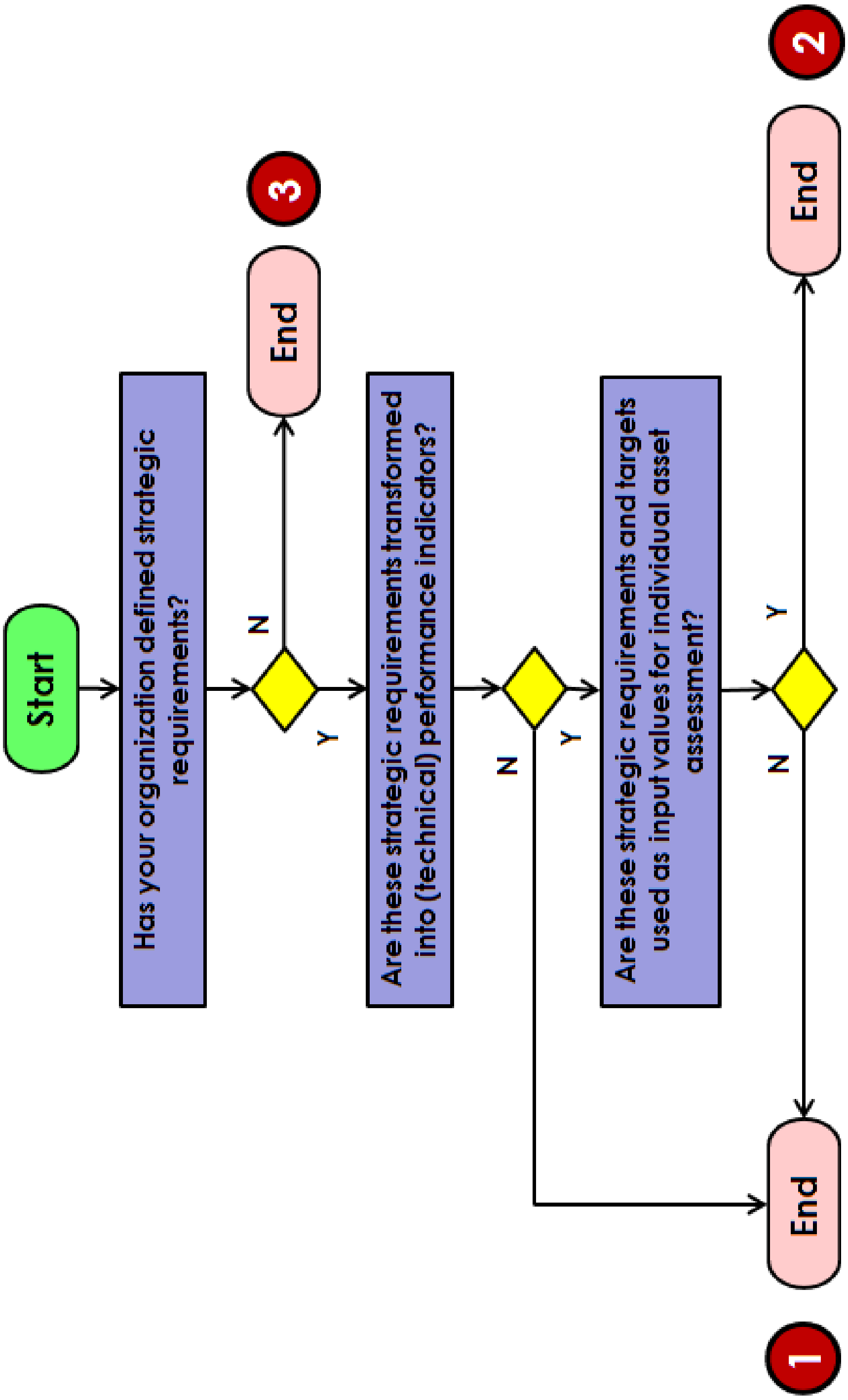


Figure 25: Flow chart for the situation analysis of strategic targets and requirements

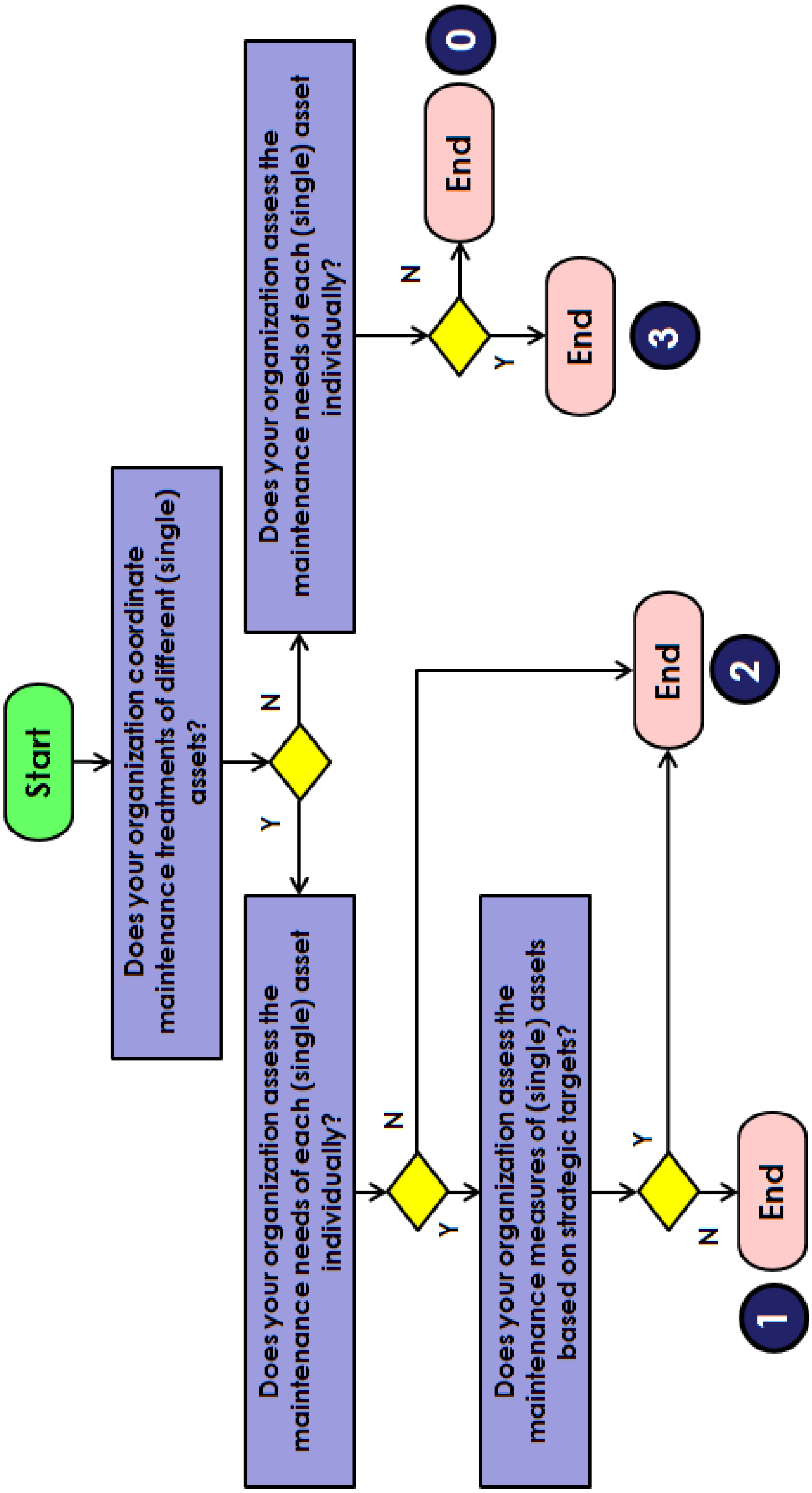
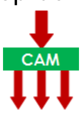
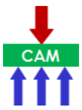


Figure 26: Flow chart for the situation analysis of cross-asset management analysis

The following assessment matrix (see Table 11) can be used to make a general categorization of the existing cross-asset management procedures into “Top-down”, “Bottom-up” or “Top-down and Bottom-up” approach.

As recommended, a combination of “Top-down” and “Bottom-up” shows a good framework for the implementation of cross-asset management procedures and optimisation. Nevertheless, the selection of the most adequate approach should be based on a detailed comparison between the pros and cons and possible consequences under the local framework conditions. Thus, the matrix can be used to compare the existing situation with the recommended one and to define the necessary implementation steps on a detailed level (see chapter 4.4).

Table 11: Assessment matrix situation analysis (numbers related to Figure 24 to Figure 26)

Approach	Organisation	Targets	Coordination
Top-down 	2	2	2
Bottom-up 	1 3	3	3
Top-down and Bottom-up 	1 3	1	1 2
No cross-asset management in place	0		0

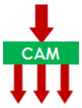
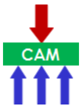
The previous categorization could also be used as a first estimation about the extent and duration for the implementation of cross-asset management procedures (see Table 12).

In general, the duration for the implementation depends on the following main issues:

- Current situation of cross-asset management and asset management (see above)
- Size of organisation (number of branches, staff, length of network, etc.)
- Number of assets to be integrated
- Number of existing processes and procedures
- Communication within the NRA
- IT-structure
- Others

The duration for the implementation of a certain approach is also strongly dependent on the starting situation and the given framework condition on the different levels. Furthermore, the number of persons to be incorporated is a decisive factor as well as difficulties due to acceptance and organisational barriers. Some of the approaches, - depending on the actual situation – require more changes in an organisation. These change processes normally take more time before the implemented procedures are fully functional and beneficial. The listed general durations for the implementation have to be seen from a relative point of view. Absolute time estimation for the duration could not be given on an objective base.

Table 12: Estimation of duration for the implementation

Approach	Duration for implementation
Top-down 	medium- to long -term[1]
Bottom-up 	medium-term
Top-down and Bottom-up 	short- to medium-term
No cross-asset management in place	long-term

1 ....not only due to technical difficulties but due to acceptance and organisational barriers

4.3 Definition of targets and objectives

The definition of strategic targets and objectives as well as the transformation of strategic PIs into technical PIs could be the most time-consuming activity in the whole implementation process. Thus, it is recommended to define the targets and requirements in the context of a stepwise process. For the implementation of strategic targets and objectives into a holistic asset management process, the following requirements have to be fulfilled to a wide extent:

- Strategic target or objective is defined within a strategic asset management plan
- The strategic target or objective is expressed by one or more performance indicators (PIs)
- The PIs can be translated into technical performance indicators (PIs)
- The technical performance indicators can be implemented into the technical assessment processes of the affected assets
- The technical performance indicators can be used to describe the effects for the different stakeholders to be taken into consideration

Of course, the targets and objectives need to be defined in coincidence with the requirements of the different stakeholders which are affected by the road infrastructure. With regard to the previous chapters, the stakeholders are classified as operators, users, neighbours, society, financing body and owners.

4.4 Implementation of new procedures and adjustment / extension of existing procedures

Based on the situation analysis and the pre-defined targets and objectives of cross-asset management, the necessary steps for the implementation of new procedures and/or the adjustment or extension of existing procedures have to be defined.

As already mentioned, the extent and duration of these tasks are strongly dependent on the amount and complexity of changes and improvements to be carried out. Thus, it will be necessary for some NRAs to integrate a comprehensive change management into the implementation process.

With regard to the recommended procedures for a holistic cross-asset management optimisation (see Figure 8), the requirements need to be brought in line with the different approaches which finally define the necessary steps for a successful implementation.

Table 13 gives an overview of the requirements, the approaches and the necessary steps for the implementation.

Table 13: Steps for implementation

Requirement	Approach	Steps for implementation
Strategic level		
Description of strategic target and requirements	Strategic asset management plan	Define targets and objectives for asset management with regard to the different stakeholders
Transformation of strategic targets into strategic (K)PIs	General and asset-specific management and business plan	Define the indicators, which should be used for the assessment of the asset management processes
Strategic to object level		
Translate strategic targets into (technical) PIs	Minimum requirements for assets, technical guidelines and standards, calculation procedures for (technical) PIs	Define technical indicators, thresholds and levels of PIs with regard to the strategic targets
Object level		
Generation list of (single) asset maintenance treatments (strategies) and calculation of corresponding PIs	Asset-specific management systems using state of the art procedures for the assessment of asset-specific maintenance treatment strategies (e.g. life-cycle-analysis)	Implement PMS, BMS, TMS, etc. (including monitoring, data repository and analysis)
Cross-asset level		
Generation of list of cross-asset treatment strategies and calculation of corresponding PIs	Process for the definition of cross-asset treatment strategies and assessment of strategies based on calculated PIs	Implement procedure for the definition and assessment of cross-asset treatment strategies
Optimisation of cross-asset treatment strategies under given requirements	Optimisation process (tool) for finding the most efficient solution under given requirements	Define optimisation problem and solution
Controlling level		
Control and adjustment	Comparison of pre-defined targets and objectives with actual situation	Define controlling instances and adjustment procedures

4.5 Control and review

Based on the experiences of the NRAs in the TAB, the continuous control of procedures and processes in the context of asset management is an essential task within a modern administration. It enables an early detection of gaps and lack of information in the data, the communication, tools, etc. and aims at a pre-active improvement of the affected procedures.

Beside corrections, each procedure has to be reviewed continuously and should focus on the questions as follows:

- Can the procedure be applied under the given requirements and is it fully implementable into the organisational structure of the NRA?
- Does the procedure give the necessary answers and does it fulfil the objectives?
- Is the input information for the practical application of the procedure available?
- Will the results of the procedures be communicated within the organisation and does the addressee use the results?

- How does the procedure affect the efficiency of asset management from the internal but also from the external point of view (taking into account the different stakeholders)?
- Which steps in the procedure and processes could be improved?

The questions described above could be used as a basis for the review and control process and have to be adapted and specified according to the local situation. Furthermore, it is recommended to apply the control and review process by an independent (in-house) consultant in form of audits and similar communication instruments.

5 Conclusion and recommendations

The objective of PROCROSS is the development of optimised procedures for cross-asset management of the total road infrastructure (including all sub-assets like pavements, structures, road furniture etc.). It aims at recommending a holistic road asset management scheme to balance the maintenance expectations of different sub-assets and stakeholders.

Based on a comprehensive investigation, which was carried out in cooperation with a high number of European National Road Authorities (NRA), the current understanding of cross-asset management was brought together providing a basis for the recommended procedures. It is important to understand that the PROCROSS approach is based on cumulated inputs and does not reflect a single approach of one road authority alone.

The Final Report (Deliverable 4) gives a detailed overview of the collected results about the use of strategic targets in the context of road infrastructure asset management, representative indicators, monitoring needs of assets and other important requirements for coordinated asset management approaches. The project revealed that many NRAs focus on different approaches and processes which can be characterized as “Top-down” (from strategic to object level), “Bottom-up” (from object to strategic level) or as a combination of both “Top-down and Bottom-up” (strategic and object level meet midway).

It is recommended to combine the maintenance needs of single assets with the strategic targets into one optimisation procedure. To enable a cross-asset management optimisation, corresponding performance indicators (PIs) must be defined on the strategic level as well as on the object (technical) level. Moreover, it is necessary to understand the translation from strategic objectives to technical indicators and vice versa. These procedures are described in detail and explained by an example using a cost-benefit optimisation approach. The optimisation methodology itself was not the main focus of PROCROSS. Putting together the procedures, mechanisms and understanding of cross-asset management in its various facets all over Europe is the main output of the project. Therefore, the Final Report describes the different steps for the implementation of the recommended cross-asset management procedures and gives an overview of possible barriers.

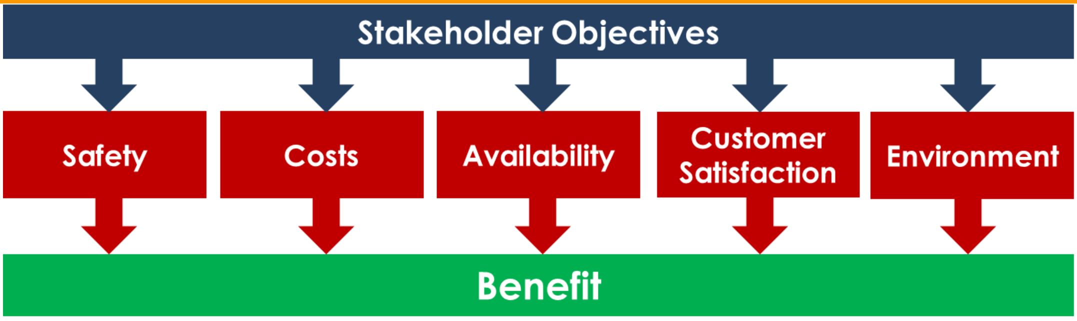


Figure 27: Benefits constituted by the stakeholder objectives.

The PROCROSS approach is based on stakeholders' objectives guiding the strategic targets. In order to measure the target achievement performance indicators are required both on a strategic and technical level (see Figure 28). The optimum solution should be the combination of coordinated maintenance activities meeting these targets and considering the individual maintenance needs on object level. Thus, the optimisation combines both, the strategic level and the object level. The optimum solution as result of cross-asset management may differ from the strategic optimum or the object optimum. In general, the cross-asset optimisation comprises the following procedures:

- Description of strategic targets and agreements with ministry;
- Translation of strategic targets to (technical) performance indicators and parameters;
- Single asset specific maintenance treatments;
- List of (single) asset maintenance treatments forming combined maintenance treatment strategies (combination of different maintenance activities on different assets within a given time period);
- The strategic target-related PIs for cross-asset maintenance treatment strategies (coordinated maintenance programmes);
- The mathematical optimisation to identify the most efficient cross-asset maintenance strategy over the whole network to meet strategic objectives.

The output of this process is a list of recommended maintenance treatments to achieve pre-defined strategic targets on the investigated network. This can be used a basis for developing coordinated short- to medium-term maintenance programmes.

The combination of Bottom-up and Top-down fulfils most of the requirements for the practical application of cross-asset management optimisation. It fulfils the needs of object level as well as the integration of strategic targets and requirements. Further, it provides a platform for the definition of cross-asset maintenance treatment strategies. The discussions within the TAB and the interviews revealed that some NRAs have already implemented such a platform, where cross-asset management is carried out be engineering insight. Mostly to define the single- or multi-year construction programs. Of course, the combination of Bottom-up and Top-down requires a basis for the communication and understanding between the strategic and the technical level. Understanding conflicts and barriers have to be incorporated into a holistic approach and can be solved by providing an objective base for the decisions. The examples showed that a simple and straightforward approach to communicate between technical and strategic layers is successful. The number of strategic objectives and targets considered and the number of performance indicators on technical level has a big impact to the complexity of such an approach. The right balance has to be found under the NRA specific asset management framework. This can lead to a more Bottom-up or a more Top-down oriented solution.

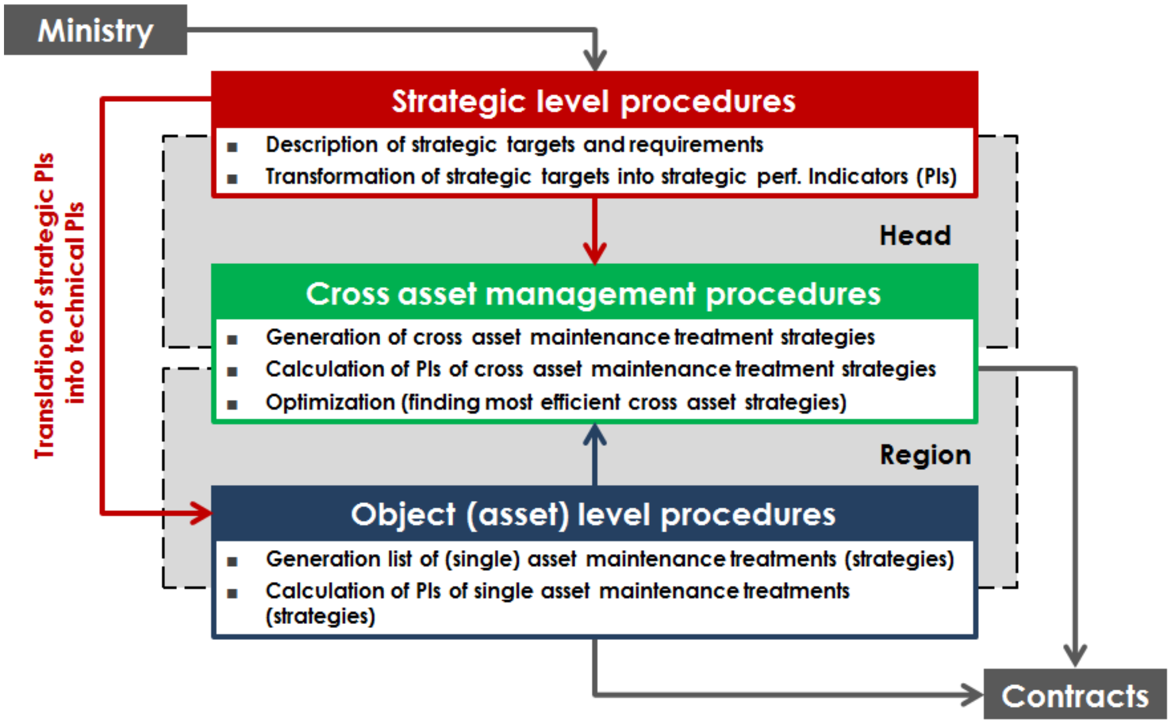


Figure 28: Cross-asset management procedures within the asset management approach

The use of indirect costs enables the translation of technical effects of maintenance treatments into monetary values and the total of all assets for the benefit definition (see Figure 27). Theoretically, the external costs can be replaced by non-monetary indicators, where the asset-specific effects have to be weighted according to the extent of target achievement before summation or aggregation over all assets. The definition of such weights could be quite complex and needs a clear understanding of the different importance or meaning of different objectives and targets (e.g. priority of safety in comparison to environment, priority of comfort in comparison to sustainability, etc.).

The optimisation routines and procedures are quite different and strongly dependent on the decision tools to be used for the different assets. The solution is a set of cross-asset treatment strategies for a road network to achieve the strategic targets considering the single asset maintenance needs. This definition leads to a quite complex optimisation problem due to the spatial and timely extent. With multiple (sometimes opposing) stakeholder objectives a multi-criteria optimisation seems to be appealing. However, the efforts and resources required to solve this problem are a good deal more than with a single objective. The connection of strategic targets to performance indicators and technical parameters as described in this report is required for multiple and single objectives. PROCROSS focuses on the framework and on influencing parameters and good practice examples; not on improving the mathematical optimisation algorithm. The optimisation approach chosen offers a solution with reduced complexity. The influencing factors are summarized or aggregated in form of combined performance indicators and constraints. This solution could be easy incorporated into existing asset management tools under justifiable efforts.

The Barriers for implementation were discussed in detail with the TAB. It is observed that the proposed cross-asset management format is extremely beneficial, but certain barriers remain for a full-scale implementation of this approach. These are:

- Although the theoretical basis of cross-asset management is robust and accommodates complexities at a large scale, it may not be practicable to consider and assess all options available. Consequently, the practical implementation requires some amount of engineering judgment.

- The time horizon and the size of the network need to be realistic in terms of the optimized solution to be of relevance. There may be options available that may be specific to the network under consideration which are not automatically identified by independent maintenance management software of sub-assets. The training and expertise of the consulting engineer is important to a certain extent in this regard in order to obtain the maximum benefit from this approach.
- The confidence of the user is key to the understanding and implementation of the method. It is important for the end-users to be able to use decisions from a cross-asset management framework for this approach to be successful. Training sessions and workshops may be of great benefit in this regard.
- An agreement regarding the objectives of the network and high-quality data about the condition of the sub-assets of the network remain key to good cross-asset management. In this regard, clear ideas from the stakeholders regarding their expectations, even at a qualitative level, is necessary. Similarly, the importance of maintaining independent maintenance management systems for sub-assets and sharing of data between different authorities is also encouraged.
- A cross-asset management approach provides a systematic method to arrive at the best possible solution in the light of existing information. However, the method is reflective of the available information and related bias. Consequently, for large bias (technical or socio-political), the approach will not necessarily lead to an appropriate intervention strategy and would simply reflect the effects of the bias.
- The time frame for the practical application of such procedures is a key task for the implementation. The procedures should not be used for long-term planning processes. They are applicable for the definition of short-term projects and schemes which combine the maintenance-needs of different assets.

Even after considering barriers such as those mentioned above, it can said that the cross-asset management format proposed here is perhaps the closest methodology which can accommodate the wide variety of maintenance management systems that exist under different roads authorities and also allow for the fundamentally different top-down and bottom-up approaches to be assimilated.

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List of Figures

List of Tables