

Computer assisted revision of infrastructure maintenance policy

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Abstract

Since 1998 Delft University of Technology develops and uses a Decision-Support System (DSS) for analysing the long-term impacts of railway design and maintenance decisions. The DSS combines data of construction, maintenance and operating, and financing processes in order to make estimates of total life cycle costs. Infrastructure performance (availability and reliability) is included in these estimates. DSS design and application, in a revision of the renewal policy for tracks and switches on the Dutch network, are presented. The DSS proved to be a valuable tool for testing the robustness of design and maintenance decisions and focusing the discussion on the important cost-driving factors.

1 Introduction

In the 1980s initiatives were and are being taken across all infrastructure-related sectors to introduce market forces. The railway sector did not escape the dance. Of all sectors, it showed worldwide a strongly declining performance in passenger and freight ton kilometres and needed increasing funding as well since the 1950s. In the European Union a reform of the state-owned, monolithic railway companies was commenced in the 1990s in order to achieve a vertical separation of the infrastructure and operations management. This separation should increase the transparency in cost accounting as well as realize more efficient and customer-oriented operations. New transport operating companies (TOCs) should be able to enter the rail market, where government-commissioned infrastructure managers (IMs) provide the infrastructure. Although the pace of transition to vertically separated railways in Europe differs from country to country, gradually a 'commercial landscape' is emerging with performance-based contractual relationships (figure 1). This is a drastic change from the integrated national railway where management on an operational level prevailed and decisions were based on 'tacit knowledge' of skilled staff.

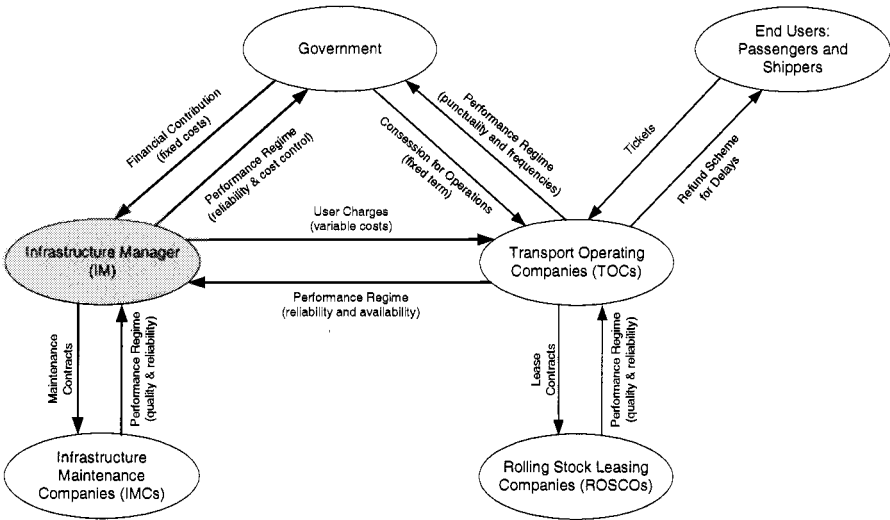


Figure 1: Contractual landscape in a vertical separated rail sector

An important consequence is that *infrastructure provision* has gained a position as a new function in the railways, performed by a separate, clearly visible *Infrastructure Manager*. This IM shares in the consequences of increasing transport and punctuality demands and the introduction of new (high-speed) transport services. Besides, it has to cope with stricter regulations related to labour safety, which require that tracks have to be taken out-of-service for most maintenance tasks, as well as pressures to reduce budgets. Finally, more and more tasks are outsourced to private companies, which requires the IM to develop the capability to control and steer the contractors' performance.

Managing infrastructure performance in terms of agreed levels of *reliability, availability, safety* and *costs of ownership* has therefore become inevitable. This strategic management level is to a great extent still an uncultivated area. The crucial issue is that the IM has to guarantee the *long-term* performance and maintainability of the rail network: short-term pressures to increase availability and reduce expenditure have to be balanced with their impacts on the long run. Strategic design and maintenance choices have a high degree of *irreversibility*: costs of modifying a design during the operational phase of a railway line are huge, while backlogs in maintenance can – after reaching certain quality levels – lead to progressive degradation and thus capital destruction. It is the task of the IM to make these consequences transparent in order to underpin design and maintenance strategies, and arrange required funding, in a quantitative, objective way.

Many IMs state asset life-cycle management (LCM) to be the correct principle for the management and provision of rail infrastructure, which is demonstrated by the development of European Standard 50126 on railway applications [1]. LCM is focused on maximization of the return on investment in the production assets owned by a company, considering the whole asset life cycle.

In order to be able to realize LCM, maintenance data and analysis methods and tools are required. During the last couple of years progress is being made in this respect, but most tools are still in an early phase of development, and successful implementations in design and maintenance management are practically absent. Most railways give a lot of attention to developing a comprehensive 'asset register', which is able to link infrastructure quality measurements, maintenance work history and transport data (tonnage) with the specific asset. This took for instance a couple of years at the Dutch IM, *Railinfrabeheer*, and still a lot of effort is required to implement the SAP system [2]. Implementation of computer-assisted maintenance planning systems, such as ECOTRACK, an expert system developed by the International Union of Railways, is now being considered by a number of railways in Europe and abroad [3].

Due to the increasing pressures from governments and operators to reduce budgets and track possession time, it is however essential to increase the quality and transparency of design and maintenance decisions more quickly. An approach is needed that can support decision-makers adequately in absence of the above-mentioned analysis and planning systems. In this paper the concept and actual use of a decision support system (DSS) is discussed, which can assist decision makers quickly in identifying long-term costs of ownership and operation (life cycle costs), caused by specific design and maintenance choices.

2 An approach to support railway design and maintenance

In order to assist decision-makers instantly in analysing the expected long-term infrastructure costs and performance, Life Cycle Costing (LCC) theory has been selected to provide the required techniques. LCC is defined as an economic assessment of an item, system, or facility and competing design alternatives considering all significant costs over the economic life, expressed in terms of equivalent currency units [4]. It contains 'approved logic' to balance costs and revenues on the short and long term.

Life cycle costs are however the result of a complicated set of (partly uncertain) conditions. An analysis of the sensitivity of the life-cycle costs to a wide range of operational conditions is required. Decision-makers are thus able to choose for a decision alternative with the best guarantee to be cost-effective and robust. The concept of a DSS can eminently contribute in this respect. A DSS can be used to improve the effectiveness and efficiency of decision makers in performing semi-structured tasks, partly having a 'judgemental' character [5]. A DSS consists of a database, a model-base, and a user-interface.

A DSS with the capability to estimate infrastructure life-cycle costs can assist in several tasks:

- evaluating different physical designs or maintenance strategies quantitatively;
- analysing the impacts of (restrictive) operational and financial conditions for infrastructure maintenance in order to discuss them with other stakeholders;
- supporting the development of maintenance plans that aim at optimising the life cycle costs of the rail system;
- training technical and financial staff in considering system wide impacts of specific design and maintenance decisions.

With these goals of application in mind, a DSS has been developed by Delft University of Technology, named *LifeCycleCostPlan*, in co-operation with several partners from the European railway sector. In the case of this DSS, 'chauffeured system use' is applied: a specialized analyst functions as an intermediary between the computer model and the decision maker.

DSS outputs are estimates on total costs of ownership during a specified period (life cycle costs), reliability and availability of the analysed segment of the rail infrastructure. Constraints, such as available budget, required safety and functionality, are not modelled in the DSS: it is the responsibility of the user to select feasible decision alternatives for the analysis. The final output is calculated in a number of steps, according to figure 2. In this figure the calculation processes are shown as a rectangular. On the left and right side the data needed for the calculations are shown. Dotted arrows indicate the use of data from a data table for the calculation, while the other arrows indicate the sequence in the calculation.

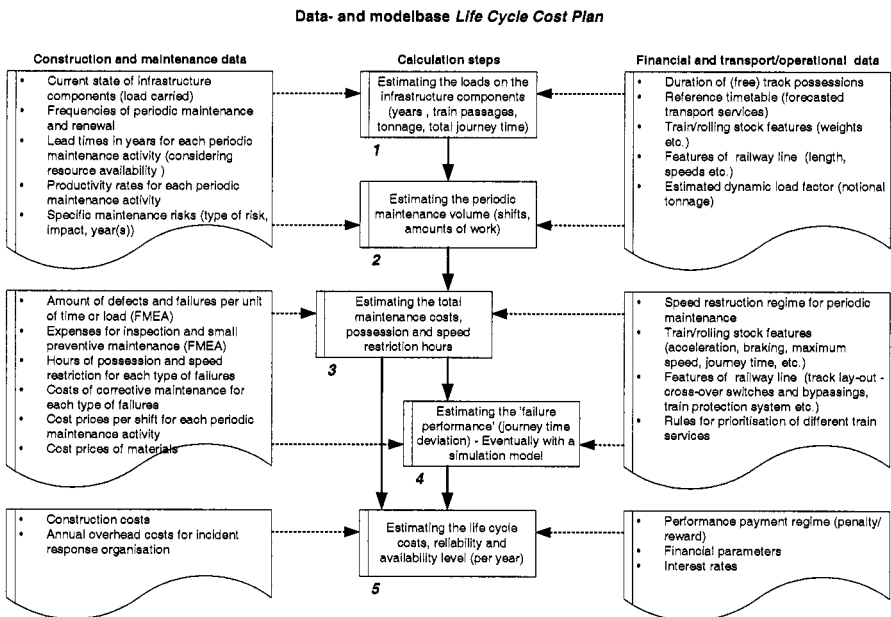


Figure 2: Structure of the '*LifeCycleCostPlan*' decision support system

A Data Collection Checklist, which describes exactly required input data and data formats, is used for the collection of input data by engineering staff. Many data sources can be used, such as empirical data (e.g. laboratory tests, computer simulation, supplier information, maintenance history and actual maintenance cost rates) and 'expert judgements' on e.g. the expected number of failures. Since maintenance analysis and planning tools have become available only recently and on a limited scale, aggregated figures on failures, track degradation and work history are hardly available or reliable.

Reliability of produced output is taken care of in two ways. First, Chauffeured Sessions are organised, where the experts meet each other directly. In the Chauffeured Sessions a process of data collection and validation takes place.

Depending on the progress, the input data itself is discussed or the DSS is used for 'real-time' analysis and validation of the assumptions ('face validity of outcomes'). Participation of experts from, at least, different organizational units is a prerequisite for the quality of the process (not a guarantee, however). Moreover, each of the participants has to make their judgements on the input parameters prior to the session. During the sessions these judgements are discussed and the participants get the opportunity to adjust their judgement or to come up with new information. In most cases one judgement results after discussion; however a range of input data can be tested as well. Secondly, the robustness of the outcomes can be assessed with the DSS itself using sensitivity analysis. The importance of a specific input variable for the overall outcome is revealed as well as the robustness of the decision alternatives: if alternatives change in rank, some of them are less robust than others. The calculation processes performed by the DSS are shortly discussed below. For each calculation process a model is used that consists of a set of equations, which is not discussed here. In [6] more details are included.

Calculation Process 1: Estimating loads on the infrastructure

Quality degradation is a function of time (years) and load on the track (cumulative gross tons or number of train passages). For the calculation of the load a so-called 'reference timetable' is used. The timetable can be specified for different time intervals and contains the expected number of trains and train-sets for the different services, specified to e.g. axle-loads and train weights, as well as the number of operational hours per day. This timetable is also used for calculating the (annual) scheduled journey time. This is the sum of the journey times for all trains on the particular track segment. 'Performance regimes' can use this as a basis for the calculation of the reliability level. The timetable also reveals the time available for track possessions that do not affect the quality of the transport services.

Calculation Process 2: Estimating periodic maintenance volumes

The second step consists of an estimation of the periodic maintenance (major works, such as rail grinding and track tamping, with intervals of more than a year). Thresholds for each major maintenance activity are specified. E.g. a higher threshold for rail renewal - 'tons carried before replacement' - reflects a lower degradation rate. The residual life spans and thus the moments for major overhaul or renewal are deducted for each infrastructure component. Besides, it can be set to realize the work during a couple of years (instead of a single year).

Figure 3 gives an impression of the intermediate output. Further, the decision-maker can label some unlikely activities, of which the possible impact should be studied, as 'specific risks'. Their contribution in the life cycle costs is shown separately. Finally, the number of shifts is calculated based on the productivity rates for each activity (net productivity, set-up and finishing time).

Calculation Process 3: Estimating total maintenance costs and 'possession hours'

Based on the number of possessions per year the total costs for periodic maintenance can be calculated based on the costs per kilometre (materials) and costs per work shift (labour and machines). A number of days with speed restrictions can be set, if applicable. The total hours of possession and speed restriction are estimated in this way.

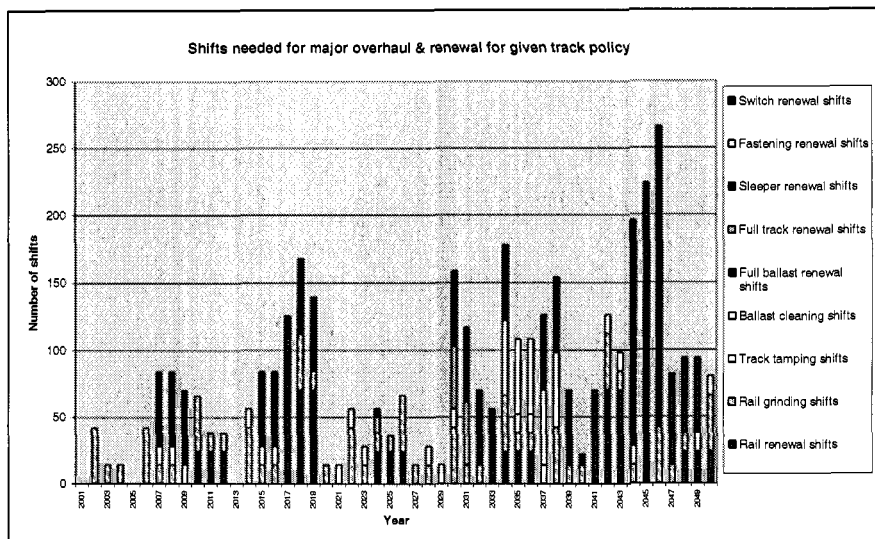


Figure 3: Planned work shifts, intermediate result after step 2

In step 3 the amount of small maintenance and number of failures are calculated as well. They are simply related to the cumulative tonnage or in-service years of the component. The user can set the costs per ton or per year for inspection, small maintenance and failure repair. Small maintenance consists of many different tasks; the summarised estimates (costs, possession and speed restriction hours) are used. Failure Mode Effects Analysis (FMEA) is the technique to be used for estimating the amount of small maintenance and failures.

Calculation Process 4: Estimating 'failure performance'

In some performance regimes the Infrastructure Manager is penalized based on the delay minutes caused by infrastructure failures. A model can be included that estimates the cumulative train delay minutes and cancellations, based on the acceleration and braking performance of the trains. The ratio of total delay minutes and the scheduled journey time in the specified time interval is the produced 'unreliability'. In other cases a cost rate is used that is simply related to the downtime (hours of unplanned and planned possession).

Calculation Process 5: Estimating the life cycle costs

In the last process the total costs of ownership (life cycle costs), and the reliability and availability estimates are made. If applicable, the construction costs are included in the total cash flows. Another choice is to include or exclude the 'specific risks' in the outcomes. Finally, the costs of financing are calculated based on the interest rate. The total life cycle costs of the different decision alternatives are finally reflected in the *performance fee*, the annuity that is required every year to finance the cash flows (interest and depreciation).

The DSS has been used in three cases since 1999, two related to the construction of the Dutch high-speed line (HSL South), and one related to the maintenance of the Dutch conventional network, which is discussed in section 3.

3 Application: supporting a revision of track renewal policy

Tracks and switches account for about 60% of total maintenance and 80% of renewal expenses on the Dutch rail network and, besides, track works need a lot of planned possessions. Not only are the expenses very high, but they can also vary a lot from year to year due to the age distribution on the network and the realization of maintenance and renewals in previous years. A timely insight into the costs and track possessions is crucial in order to level out the renewal volume over the years. Insight into the life cycle costs of different renewal strategies enables an optimal prioritisation between planned projects [7].

In 1999 a prognosis showed a strong increase in the renewal volume required between 2000 and 2010. Besides, in 2000 the Infrastructure Manager, Railinfrabeheer, and the Ministry of Transport decided to renew about 890 kilometres of so-called 'Nefit-track' before the year 2007 due to the fact that the quality deterioration of the fasteners proved to become hard to control. This causes even more, unprecedented renewal volumes. Halfway the year 2000 this was an important trigger for *Railinfrabeheer* to start the 'Life Cycle Management Plus' project. Objective of LCM+ was to develop smart *maintenance policy rules* for tracks and switches that:

- lead to an important reduction and levelling out of the renewal volume;
- are cost-effective in terms of reduced life cycle costs and possession time.

A prerequisite for new policy rules to be accredited was that the cost-effectiveness had explicitly to be demonstrated and tested for a wide range of situations and future conditions, which is why it was decided to support the process with the *LifeCycleCostPlan* DSS. Besides staff from Headquarters, four sub-teams of technical track specialists and planning analyst from every Maintenance Region were participating to develop and assess cost-reducing strategies. This configuration of the project team, consisting of about 15 members, should guarantee the reliability of maintenance estimates.

In the first project phase a top-30 of about 80 promising measures was composed during a computer-supported brainstorm session. Selection criteria were not only cost-effectiveness, but also feasibility (implementation time) and market conformity (acceptability for transport operators and Ministry of Transport). It included 'lighter' track designs for low-density lines (UIC class 6), life-lengthening maintenance (or: controlled postponement of renewal), and 'instant re-use' of main-track components and switches on low-density lines. In this last case components are taken out, transported and re-installed in a single night.

In the second project phase the regional sub-teams assisted in the life cycle cost analysis with the use of the Data Checklist for a number of 'pilot projects'. In total nine projects were selected in order to represent the diversity of track and switch types as well as the different operational features (main track, side-track and yards). Most pilots were preliminary scheduled for renewal in 2002. The regional teams had to develop feasible maintenance and renewal strategies. Data was processed in the *LifeCycleCostPlan* DSS. Subsequently, the assumptions and results were discussed in a number of Chauffeured Sessions with participation of all experts involved in order to improve the consistency of the estimates.

In the third phase an extensive sensitivity analysis was performed for each pilot with *LifeCycleCostPlan*, in order to test the robustness of the strategies under different operational conditions (e.g. increased or decreased tonnage, renewal cost rates, and interest rates). This also assisted the deduction of policy rules, which were applicable to a wide range of situations on the network. This phase was finished with a Policy Session, in which the results of the analyses were discussed with the experts. This finally resulted in sixteen rules being acceptable to all Maintenance Regions. In the fourth phase the impact of the new rules was quantified in an adapted Renewals Prognosis 2003-2020.

As an example one pilot is discussed in more detail. This pilot focused on a track section with a length of 5 kilometres. This railway line is only used for passenger traffic with a low annual tonnage. During night tracks are available for maintenance. The rail type used is NP46, an old Dutch standard which can still be found on 45% of the entire network, especially on low-density lines. With respect to the section analysed 3250 meters is CWR with hard-wooden sleepers laid in 1970, 700 meters is CWR with soft-wooden sleepers, and 1000 meters is jointed rail on hard-wooden sleepers. Promising strategies identified were:

- SOLUTIONS 1 and 2: Keep the NP46 rail type in tact by placing new hard-wooden sleepers and a new ballast bed; the whole track is made continuously welded. Solution 2 uses re-usable sleepers with reduced acquisition costs but a shorter life expectancy.
- SOLUTION 3: Full track renewal and upgrade to UIC54 rail type with concrete sleepers. This was the initial solution chosen.
- SOLUTIONS 4, 5 and 6: Application of life-lengthening maintenance on the hard-wooden sleepers (using coils) and a replacement of soft-wooden sleepers. After 5 years solutions 1, 2 or 3 is applied.

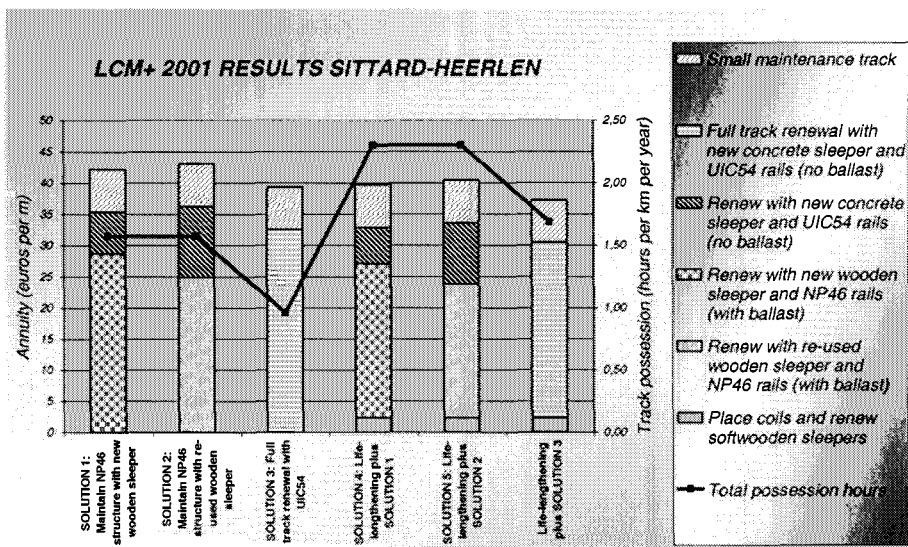


Figure 4: Maintenance and renewal solutions for NP46 tracks (INDICATIVE)

Figure 4 shows the required annuity for the (organizational) planning horizon of 50 years. Each of the bars shows the cost elements, of which this annuity is composed. Further, the line depicted presents the (average) annual amount of hours needed for maintenance.

The life cycle cost analysis showed solution 6 (life-lengthening maintenance for the first five years and a full track renewal with UIC54 rails and concrete sleepers) to be the best solution. As figure 4 shows this leads to a saving of more than 5% with a real interest rate of (only) 3%. Relatively a lot of track possession for maintenance is needed, which is in this case however *not* a major obstacle as there are no trains running during night and set-up activities are not needed (i.e. the life-lengthening maintenance can be fit into 'slots' with a short duration). The robustness of this outcome can be shown for low-density lines in varying operational and physical situations as well, which led to the development of two rules related to NP46 tracks:

- All NP46 tracks have to be replaced by the UIC54-track with concrete sleepers if a renewal of sleepers has become unavoidable: this will result in the lowest life cycle costs. Ballast is renewed simultaneously.
- The lifespan of low-density NP46 tracks with hard-wooden sleeper is to be extended by at least five years using coils. Soft-wooden sleepers are to be removed completely and the rails have to be made CWR.

Instead of applying the standard renewal policy (solution 3) these 'smart rules', which take the local operational situation into close consideration, prove to be both attractive for reducing life cycle costs and for reducing and levelling out the short-term renewal budget, without endangering safety and reliability levels.

LCM+ was finished in 2001. A new prognosis for the years 2003-2020 was developed, based on cautious assumptions on the applicability of the rules. A reduction of the annual renewal budget by 10% or about 20 million Euros is forecasted, including extra maintenance expenses. At the moment implementation of the rules, which have been accredited by the Central Management, is performed: LCM+ has its consequences for the procedures and information exchange in the planning of maintenance and renewal works. Also a regular review and update of the policy rules is taken care of.

4 Conclusions

Life cycle management (LCM) has remarkably long been a neglected area of competence, not only in the railways but also (to a lesser extent) in other capital-intensive industries [8]. However, systematically considering future maintenance consequences of infrastructure designs and maintenance strategies can lead to important savings in costs of ownership. Dekker and Van Noortwijk [9] conclude that there is still a need for simple, scientific methods for optimising maintenance in relation to total life cycle-costs, especially for civil assets, such as roads and railways. The restructuring of Europe's railways has been a trigger to develop such methods. The new Infrastructure Managers face increasing demands related to costs, reliability and availability of the infrastructure, requiring a more transparent decision-making process.

In this paper a life cycle costing (LCC) approach has been elaborated that should assist decision making on railway designs and maintenance strategies. The use of a decision-support system (DSS) should enable an evaluation of alternative courses of action on their consequences in terms of infrastructure cost and performance levels in order to select the most cost-effective and robust alternative. Only a few railways have now reported that such computer-based applications have been used for analysing long-term costs and performance of railway tracks, i.e. Austrian, French, German and Dutch Railways [10; 11; 12; and 6].

The application of the DSS, described in this paper, during a maintenance policy revision at the Dutch Railways has shown that the DSS helps in prioritising investments and developing sound maintenance strategies. Although it can be the case that the 'best solution' requires more budget than available, the analysis still provides the insights to select a 'second-best solution' with the less damaging impacts on the long run. Further development of the DSS could focus on methods to manage and improve this process of participation. Moreover, 'probability analysis' techniques (e.g. Monte Carlo simulation), benchmarking with other railways, and the consultation of external experts could improve the confidence in life cycle cost analyses further.

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