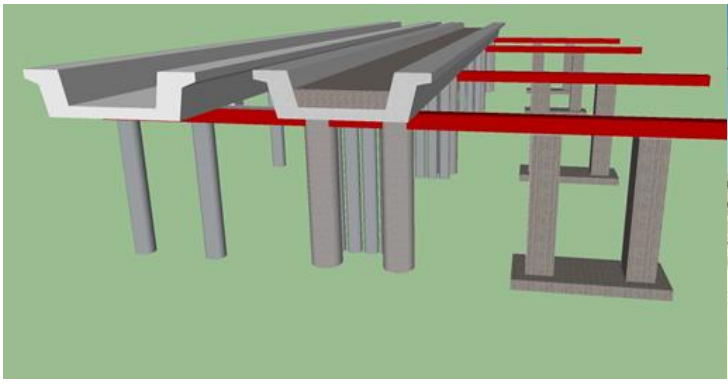
MAINLINE

MAINtenance, renewal and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts

Collaborative project (Small or medium-scale focused research project)

Theme SST.2011.5.2-6.: Cost-effective improvement of rail transport infrastructure



Deliverable 3.4:
Guideline for replacement of elderly rail infrastructure

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Abstract of the MAINLINE Project

Growth in demand for rail transportation across Europe is predicted to continue. Much of this growth will have to be accommodated on existing lines that contain old infrastructure. This demand will increase both the rate of deterioration of these elderly assets and the need for shorter line closures for maintenance or renewal interventions. The impact of these interventions must be minimized and will also need to take into account the need for lower economic and environmental impacts. New interventions will need to be developed along with additional tools to inform decision makers about the economic and environmental consequences of different intervention options being considered.

MAINLINE proposes to address all these issues through a series of linked work packages that will target at least €300m per year savings across Europe with a reduced environmental footprint in terms of embodied carbon and other environmental benefits. It will:

- Apply new technologies to extend the life of elderly infrastructure
- Improve degradation and structural models to develop more realistic life cycle cost and safety models
- Investigate new construction methods for the replacement of obsolete infrastructure
- Investigate monitoring techniques to complement or replace existing examination techniques
- Develop management tools to assess whole life environmental and economic impact.

The consortium includes leading railways, contractors, consultants and researchers from across Europe, including from both Eastern Europe and the emerging economies. Partners also bring experience on approaches used in other industry sectors which have relevance to the rail sector. Project benefits will come from keeping existing infrastructure in service through the application of technologies and interventions based on life cycle considerations. Although MAINLINE will focus on certain asset types, the management tools developed will be applicable across a broader asset base.

Partners in the MAINLINE Project

UIC, FR; Network Rail Infrastructure Limited, UK; COWI, DK; SKM, UK; University of Surrey, UK; TWI, UK; University of Minho, PT; Luleå tekniska universitet, SE; Deutsche Bahn, DE; MÁV Magyar Államvasutak Zrt, HU; Universitat Politècnica de Catalunya, ES; Graz University of Technology, AT; TCDD, TR; Damill AB, SE; COMSA EMTE, ES; Trafikverket, SE; Cerema (ex SETRA), FR; ARTTIC, FR; Skanska a.s., CZ.

WP3 in the MAINLINE project

The main objectives for WP3 are to:

- Investigate new construction methods and logistics for transport that minimize the time and cost required for the replacement of obsolete infrastructure. The focus here is on cost effective and environmentally sound methods that are easy to implement with low impact on the rail traffic and a short down time of the network.
- Plan and optimize the construction processes on existing lines where replacement of existing infrastructure is an alternative. Here the systematic approach is extremely important. The results will help the infrastructure manager to decide for the most favourable measure from technical, environmental or cost demands.
- Deliver input regarding data to the development of life cycle cost models and other decision support systems for infrastructure managers. This includes taking into account construction time and logistics, short- and long-term impact on the network, future maintenance.

The pictures on the cover illustrate methods to exchange bridges and track.

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Glossary

Abbreviation/ acronym	**Description**
α - factor	Factor to adjust characteristic values for vertical load to actual rail traffic. α ranges between 0.75 and 1.46 with 1.33 as the normally recommended value.
CEN	European Committee for Standardization
DB	Deutsche Bahn – German IM
D-B	Design & build (a project delivery system)
DoW	Description of Work
EC	European Commission
BDK	Banedanmark
IM	Infrastructure Manager
IS	Intermediate Support
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LCAT	Life Cycle Assessment Tool
M&R	Maintenance and Renewal
OHLE	Overhead Line Equipment
ÖBB	Österreichische Bundesbahnen – Austrian IM
RC	Reinforced Concrete
RILEM	International union of laboratories and experts in construction materials, systems and structures
SB	Sustainable Bridges, EC FP6 Project
SBB	Schweizerische Bundesbahn – Swiss IM
SPMT	self-propelled modular transporter
TCDD	Türkiye Cumhuriyeti Devlet Demiryollan – Turkish IM
TecRec	Technical Recommendation approved as standard by UIC and UNIFE
TOC	Train Operating Company
TRV	Trafikverket – Swedish IM
TSI	Technical Specification for Interoperability
TSR	Temporary Speed Restriction
UBM	Under Ballast Mat
UIC	International Union of Railways
UNIFE	Association of the European Rail Industry

URP	Under Rail Pad
USP	Under Sleeper Pad
WP	Work Package

1. Executive Summary

This report gives advice on how to choose the most suitable method for bridge and track replacement activities on operational railway networks. It will assist IMs in the evaluation of, and selection from, the wide range of possible replacement methods presented in the previous deliverables from WP3: ML D3.1 (2013) Benchmark; ML D3.2 (2014) Bridges and ML D3.3 (2014) Track.

An important consideration in replacing elderly infrastructure within the railway environment is track access since this is the major source of income for railway administrations and can be an important factor in national economics. Consequently it is important to reduce any downtime period by planning and optimizing the construction processes, even though this may lead to somewhat increased investment in terms of labour, temporary solutions and machinery. Here a systematic approach, which should always be connected to life cycle assessment, is extremely important. Hence, the focus of this report is on cost effective and environmentally sound methods that are easy to implement with a low impact on rail traffic through short network down time that will help the IM to decide on the most favourable measures based on technical, social, environmental or cost demands.

First the planning process is treated in chapter 4 and Appendix A. Then guidelines are given on bridge replacement in chapter 5 and some examples of standard bridges are presented in Appendix B. Track, Switches and Crossings are presented in Chapter 6. The report also presents a proposal for a rough estimation of track possession costs and related parameters which can be used where no formal method of calculation is used in Appendix C.

2. Acknowledgements

This present report has been prepared within Work Package WP3 of the MAINLINE project by the following team of contractors with Lulea Tekniska Universitet (LTU), Sweden, as task leader:

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- Trafikverket (TrV), Sweden (Anders Carolin, Björn Paulsson, Magnus Edfast)
- Skanska a.s, Czech Republic (Tomáš Krejčí)

3. Introduction

This report is addressed to the asset maintenance engineers within the railways infrastructure owners or working for consultants and others involved in the planning and design of the renewal of railway bridges and track.

Bridges and track can be replaced in numerous ways and different countries in Europe tend to have a different set of most practised methods. This report tries to give guidance on how to choose the best method for every individual replacement work and also includes a description of a project management process for replacement techniques (chapter 4) intended to ensure a planning process of high quality.

The availability of the network is very important for the IM: regional differences and special demands vary and influence the internal decision on the availability and length of possessions and speed restrictions. Therefore this report also offers a discussion on track possession cost in Chapter 4 and Annex B, where indications on the cost drivers used to calculate track possession cost can be found.

On existing lines the construction process needs to be planned precisely. Here the systematic approach is extremely important and a proposal how to manage complex construction process is given in Chapter 5.2.

In the following chapters important key parameters for the construction site itself are presented. Based on these indicators a decision support for different available techniques is given in Chapter 5 for bridges and Chapter 6 for track. The focus is on cost effective and environmentally sound methods that are easy to implement with low impact on the rail traffic and a short down time of the network.

In Annex A some examples of standard bridges are presented.

As in the previous reports the focus is on the improvement of logistics in terms of bridge and track replacement. With precise scheduling of the construction process and an integrated planning process maintenance activities can be enhanced. Different strategies and good practices of the European Infrastructure Managers (IMs) for replacement of track, switches and crossings are presented in Chapter 6.

The methods discussed in this report provide a compilation for Eastern European railways showing various proven techniques that can be adopted for any network that significantly changes within a short time. Many methods shown in the report can easily be adapted (without any major material consumption or logistic challenge) from one country to another. A significant risk minimization can be obtained by using best practice methods. Revealing the advantages of the individual methods an individual LCCA will be able to deliver input regarding data to the development of life cycle cost models and other decision support systems for infrastructure managers.

This deliverable is the final output of work within WP3 and feed into WP5, Task 5.5, which is to produce the MAINLINE Life Cycle Assessment Tool (LCAT).

4. Planning process

4.1 General

Any construction activity (assessment, strengthening or renewal) within a railway network influences the availability of tracks.

Planning replacement activities in the railway environment is a complex task. Different disciplines, building activities, track works and signalling etc., have to be coordinated. Furthermore, the rail traffic is temporary interrupted or there is severe disturbance. For a normal situation the available capacity is used to a quite high degree with limited tolerance for disturbance.

Actual traffic needs to be considered in planning and certainly any future plans for the line concerned. Long-life assets like bridges need to meet a long-term strategy. In railway terms this means that any plans to increase speed, axle loading or successions of trains within the next 60 - 80 years should preferably be known when replacing a bridge. Different railway networks and rail traffic situations have to be considered. For example, known changes in line categories, becoming part of transnational corridors (either freight or passenger trains) must be considered. This is an important rule when deciding on design parameters as the α-factors for load, which adjust characteristic values for vertical load. to actual rail traffic (α ranges between 0.75 and 1.46 with 1.33 as the normally recommended value). Also the necessary compliance with Technical Specifications for Interoperability (TSI) is important. At a very early stage (~ 5 to 6 years prior to replacement activities) any activity influencing track availability should be declared. In this way it can be ensured that replacement works and corresponding track closures can be included in timetables.

In Table 4-1 it can be seen that track closures between 14 to 100 hours are commonly available for replacement work in different railways.

Railway (country)	Period	Remarks
Ceské Dráhy CD (CZ)	60 hours	Typically during weekends
Network Rail Infrastructure Limited (UK)	60 – 100 hours	Typically during Easter or Christmas
Deutsche Bahn AG (DE)	60 hours	Typically during weekends
Banedanmark (DK)	120 hours 56 hours	Typically during Easter Typically during weekends
Administrator de Infraestructuras Ferroviarias ADIF (ES)	60 hours	Typically during weekends
Trafikverket (SE)	16-24 hours or 2x7 hours	Typically during weekends. Longer possession for bridge replacement carrier or two shorter with use of temporary bridge.
Türkiye Cumhuriyeti Devlet Demiryollari Isletmesi TCDD (TU)	2x7 hours	with use of temporary bridges and speed restriction

Table 4-1 Typical track possessions for replacement works

4.2 Track possession cost

4.2.1 General

The policy relating to the costing of, and charging projects for, track possessions and temporary speed restrictions differs across Europe. In some countries legal contracts between the infrastructure manager (IM) and train operator(s) define the cost payable by the IM to the train operator(s) for traffic disruption. In other countries the theoretical cost of disruption may be calculated but no payments made and in some cases no attempt is made to quantify these costs. Some contracts with train operator(s) include penalty payment from the IMs when track possession is not guaranteed. Costs can vary by time of day or time of year and also to reflect the importance of the route to the national economy.

Disruption costs can have a major bearing on the whole life costing associated with infrastructure maintenance and renewal work and are taken account of in the MAINLINE LCAT tool (ML D5.5). In order to minimize these costs planning of maintenance activities and their potential impact on the timetable need to be undertaken well in advance of the proposed works.

Good pre-planning helps to identify the length of track closure required so that timetable alterations can be advertised in good time to minimize the inconvenience to users of the railway. Once an appropriate track possession has been agreed the detailed planning of the work can be started. This implementation planning phase considers more details and looks closely at the construction process and logistics. Here the surroundings and train traffic play an important role. Methods that fit in the time planned can be compared, evaluated and priced accordingly. Production phases are calculated in more detail: prefabrication and on-site methods are compared. A construction time plan within the agreed track possession is outlined.

To enable IMs to estimate their hindrance costs section 4.2.2 explains the main parameters, identifies the most important and gives recommendations on their evaluation. Appendix C gives examples of hindrance costs actually used by some IMs and also suggests a simplified methodology that can be used in the absence of actual cost data. These examples also illustrate how planning well in advance of the works can influence the different factors.

4.2.2 Operational hindrance cost

When railway operation is disturbed by hindrances or disruptions, this leads to extra cost and revenue losses compared to undisturbed operation.

This chapter will try to help to calculate the cost of planned unavailability of track due to maintenance or renewal activities and not look at unexpected disturbance or accidents.

<u>Reasons for</u>

- (partial) closures due to works,
- Speed restrictions due to works,
- Disruptions in operation,
- Propagated delays

The operational consequences of non-availabilities such as delays, detours, replacement services and many more, are input parameters for the calculation of the operational hindrance costs. And they can be roughly divided into cost that infrastructure managers IM or operators have:

<u>Cost for infrastructure managers (IM)</u>

- Production of a timetable for the construction period
- Penalty to customers and/or vouchers for passengers

Cost for railway companies (operators)

- Higher payments for employees (train driver, conductor are longer on duty)
- Cost for rail replacement bus services
- Higher maintenance caused by longer journeys in rerouting
- Higher power consumption

Losses for both IM and operators

- Loss of passengers reduced profits

If operational hindrance costs are to be taken into account for a system optimisation, only planned disruptions following infrastructure measures are relevant. These result in direct costs as well as in a greater organisational effort.

These effects are highly cross-linked, so they can be either a direct consequence of an operational hindrance or effected by another consequence. These interdependencies differ by the line involved, the design operational programme as well as the immediate management of the operational hindrance.

For a serious evaluation of cost for track possession the traffic load, the length of the track closed, the train type mix, and the distribution of trains across day and night need to be taken into account. Figure 4.1 below shows typical track loads in Austria for different lines and one can see that the traffic will influence the choice of method, EBW (2011).

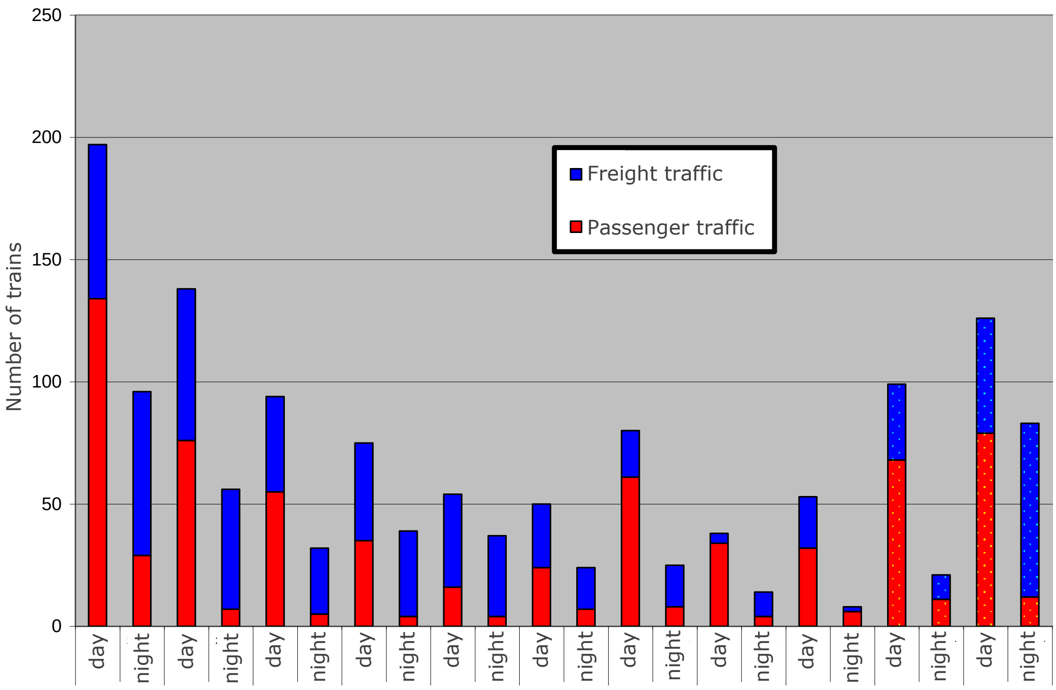

Figure 4-1 Typical number of trains on representative lines, distribution day/night, EBW (2011)

The individual importance of the line is difficult to determine. Regional trains on one hand and long distance trains including cargo trains on the other hand will influence the decision. The importance of commuter trains for the economy needs to be considered. Rerouting and redirecting passengers by bus are often impossible due to lack of capacity of streets and existing bus lines. Freight trains without rerouting possibilities must also be considered.

With consideration to regional aspects such as rerouting possibilities, traffic intensity, available space, bridge complexity et cetera the current practice is that the typical time given for a bridge replacement differs between countries. And often the importance of the line and other special demands define the internal decision for the length of the track possession available and strongly influence the planning process to find the optimal solution.

4.3 Environmental issues

Nowadays environmental aspects are becoming more and more important and relevant to infrastructure projects. Not only the use of resources needs to be considered but also the safety of humanity and wildlife become more important.

When planning to maintain or replace infrastructure these aspects need to be considered in an early stage (refer to Appendix A Phase 2). Biological analysis, counting of rare or protected animals and the reduction of noise aspects are a time consuming and sometimes multilateral tasks. Therefore it is necessary to include these questions early in the planning process. National regulatory procedures may give assistance to include all aspects.

4.3.1 Available methods to reduce noise

Particularly noise has been a growing and challenging issue on track. According to a 2013 roadmap on noise generated by rail freight wagons “the Commission regularly receives letters from local authorities and citizens' group affected by high level of rail traffic (especially from Germany and the Netherlands) asking for further EU action to reduce noise levels.” EC Roadmap Noise (2013).

Therefore this sub chapter provides proactive and interceptive solutions for noise reduction. When active measures on the track or other parts of the railway infrastructure cannot be realized passive noise protection measures are carried out. Then for example soundproof windows or facade proofing can be made. Especially in existing rail routes a combination of active measures and passive measures are implemented to protect people and residential properties.

General one can say that sound is the disturbance of a longitudinal wave pressure in the solid medium. Thus the reason for noise is vibration. Substantially we can say that the higher the vibration the higher the noise. For railways vibration is one of the main degradation mechanisms or the result of poor maintenance with flat wheels or wear at the rail. Thus higher dB of noise than the normal average value is also an indicator of poor maintenance.

First of all one can say that maintenance is very important: a track in good condition is much more silent compared to a less maintained track. Researchers have showed that ‘Corrugated wear of running rail surface can cause the rolling noise 20dB (A) greater than the smooth rail,’ Tomičić-Torlaković and Stefanovic (2010). Generally the maintenance level should take into account the train load, speed and frequency of trains.

In Germany under certain conditions where constant noise reduction is a problem one can additionally use the "Especially monitored track". As mentioned above a smooth surface of the rail is important for the prevention of noise at the source. For this reason, the noise control measures in challenging sections are particularly supplemented by monitoring the track: A special train regularly checks the condition of the rail surfaces on their acoustically relevant state. When the measured track values exceed the requirements, the surface of the rail head is ground. Thus, a permanent noise reduction of 3 dB (A) is obtained.

Noise barriers

Along new lines and also while upgrading existing railway lines noise barriers are the most common form of proactive protection against noise. They are mainly highly absorbent aluminium walls with heights between 2-4 meters. The height depends on the required noise reduction.

Figure 4-2. Types of noise barriers aluminium elements and gabbions [source: FERRONDO Projekt]

Other systems like concrete walls and transparent fibre frames are also in use.

Moreover the German Railway (DB) has developed and tested landscape friendly walls. So called gabion walls (wire baskets filled with natural stones) [see Figure 4-2] and very low noise protection walls near the track (with heights from 55-74 cm) also reduce transmission of generated noise at the wheel/rail interface effectively.

Figure 4-3 Very low noise protection wall [source: Ingenieurbüro Lutzens]

Under Sleeper Pads (USP)

Further noise reduction can be achieved by using non-conventional solutions such as Under Sleeper Pads (USP), ballast mats, rail fastenings and rail damping devices. Noise amplitude is greatly variable with speed, temperature, maintenance of rail and rolling stock (brakes, engine etc.). Also elastic pads and rail damping devices performance on attenuation depends on the temperature. The optimum working temperature should be between -20^{O}C and +40^{O}C. Two research reports show that rail dampers can achieve 6dB reduction in noise at the most optimum condition and 4dB on average, Ahmad et al (2009), Betgen et al (2013).

Under Sleeper Pads (USP) are elastomeric elements placed under the sleepers that provide higher elasticity to the track. As a result of diminishing track bedding modulus, there is an increase of the load distribution, which reduces the stress applied onto the ballast and hence, its deterioration. This load-distribution effect does not only imply that a higher number of sleepers are involved in the load transmission but also that the effective area of sleeper applying the load is increased, avoiding hollow areas under the sleepers.

As a result of reducing the contact pressure of the sleeper and the ballast, there is a deceleration of ballast degradation and therefore, track geometry deterioration. ÖBB have monitoring for years the degradation of track and turnouts provided with USP, and concluded that by using USP, LCC cost could be reduced by 13 to 15%. For that reason, only from 2002 to 2007, 87 turnouts were installed on the ÖBB network using USPs.

Apart from reducing LCC, USPs have also other important advantages such a reduction of the vibration level transmitted to the ground and irradiated noise. Measurements have shown a reduction of vibrations in the 40Hz-50Hz frequency range.

In Germany USP are mandatory for new build bridges and yet often used when track is renewed on existing bridges.

Methods for bridges

Bridges can also have noise problems. The main source of noise radiators can change from one bridge to another. There is not a certain part that can be stated as noise radiator on bridges. However one main source of the vibration is track and train interaction that creates mechanical waves in the medium as pressure and displacement varies.

Therefore the same solution as for track noise reduction will also reduce the bridge noise. One of the common noise radiators in bridges is the girders and the base. If the vibration can be decreased before entering the bridge noise will be reduced in a much more efficient way in a faster time. This could be done by attenuating noise at the source. One study showed that "The final measurements have shown that the average vibration and noise levels were reduced by 5 to 8 dB" in a 451m steel bridge in Budapest by using a company tuned absorber, that is fixed to the rail web, Augusztinovicz et al (2003, 2006).

5. Bridge Replacement

5.1 General

The need to replace a bridge can have different causes. One common cause is that the bridge has reached its technical and/or economic life length. The rationality of this are discussed in other deliverables of this project: ML-D1.4 (2014) “Benchmark of new technologies to extend the life of elderly rail infrastructure” and ML-D5.7 (2014) “Manual for a Life Cycle Assessment Tool (LCAT)”. However, replacement can also be initiated by the upgrading of a line or acute situations such as accidental damage.

In a survey of European railway bridges in 2004, it was found that 62 % of the bridges had a span less than 10 m, 34 % had spans between 10 m and 40 m, and only 5 % had spans longer than 40m, SB-D1.2 (2004). Therefore one can say that most of the bridges that need to be replaced in the existing networks are small and medium span bridges and for those types techniques are evaluated in this guideline.

Replacement of bridges can be done in various ways. Some of the most common methods are described in the earlier deliverables of this project, ML-D3.1 (2013) “Benchmark of production and replacement of railway infrastructure” and ML-D3.2 (2014) “Methods for bridge replacement”. Here these methods will be summarized and some recommendations will be given regarding their use.

First in chapter 5.2 an example of a management procedure for replacement is given. Then in section 5.3 replacement of the superstructure for short spans is presented with summarized recommendations regarding available methods for different site conditions. In section 5.4 full replacement of short spans is discussed whereas replacement of long spans is discussed in section 5.5. In section 5.6 substructures and abutments are discussed. Some examples on the design of standard bridges with short spans are given in Appendix B.

5.2 Management and Procurement of replacement projects

In order to choose the most ideal method for replacement, it is necessary for the IM to manage the project through all steps.

Many IMs directly employ staff to undertake routine maintenance activities and these can be used to undertake asset replacement as well. When this is coupled with an in house design capability the question of how to procure the services of an external supplier may only arise on a limited number of occasions when the scale of a project is beyond the resources locally available or specialist work is to be undertaken. In other cases IMs may utilise external suppliers to undertake virtually all maintenance and replacement activities on their networks.

In the UK, the IM, NR, tend to use a “design and build” contract let to a contractor, who then employs either an in house or external designer.

In Turkey, the IM, TCCD, often considers 3 alternative designs with varying construction procedures, aesthetics and costs and then chooses the best alternative among the three.

There are a number of different procurement routes open to IMs when they wish to procure the services of an external supplier for construction activities which are illustrated in Figure 5-1.

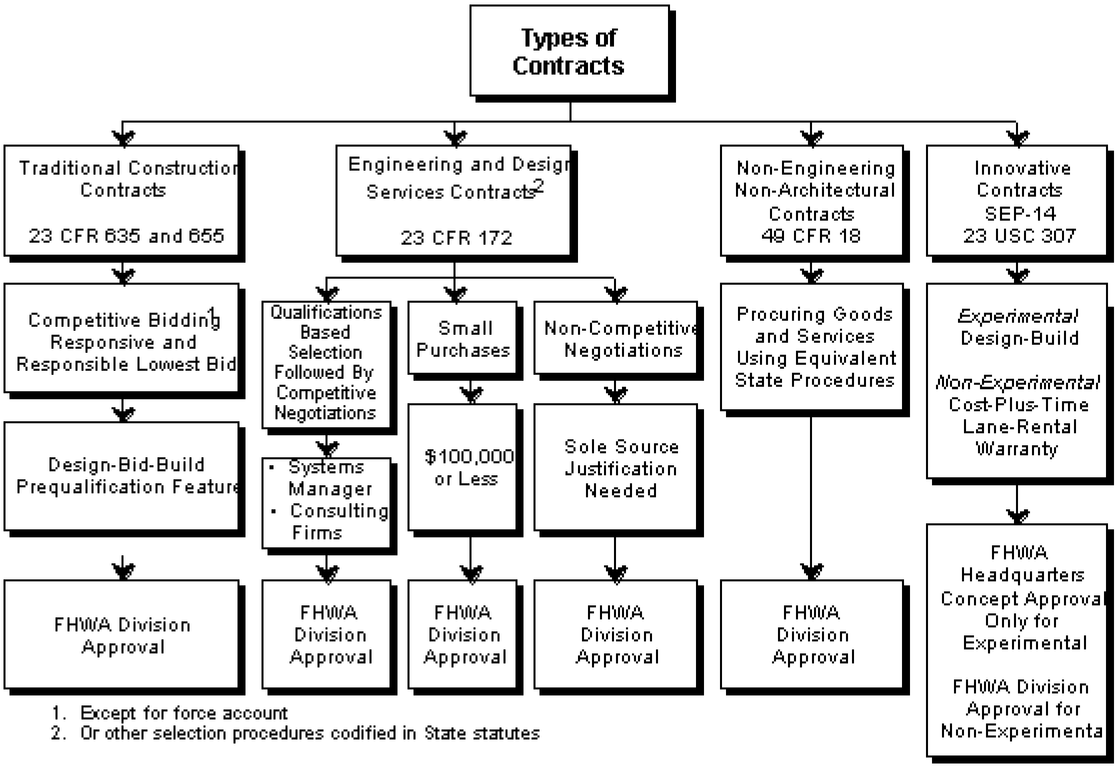

Figure 5-1 Types of construction contracts (source: http://ntl.bts.gov/lib/jpodocs/repts_te/3029/image1.gif)

The more popular of these, design-bid-build and design-build are discussed below. Further advice can be found at www.constructingexcellence.org.uk/pdf/fact_sheet/procurement.pdf.

The cross-regional bundling of construction capacities offers benefits for IMs as well as for contractors. By combining several renewal or maintenance works, the “time loss” due to the transport and set-up of the machinery is minimized, which results in an increase of work and cost-effectiveness. By increasing the “productive working time”, contractors are able to reduce the unit price of the service, which benefits IMs, while their profit increases as a result of higher machine outputs.

Design-bid-build

Under this process the IM appoints (or tenders) a consultant to design the project and prepare contract documents in accordance with a pre prepared brief and then invites tenders from a number of suitably experienced contractors. The contract is then awarded to the contractor who makes the most acceptable offer and construction work is overseen either by the IM or the design consultant.

The assessment of tenders was traditionally based solely on price but there is now a tendency to judge tenders under a two stage process where the quality of the proposed working methods are first assessed and costs considered later. Quite often a weighting factor is applied to give the quality considerations a greater importance than the price.

Under this system it is also possible for a tenderer to propose an alternative solution to that produced by the designer if he thinks that it will provide a higher quality result or be cheaper or quicker to construct.

Disadvantages (http://en.wikipedia.org/wiki/Design%E2%80%93bid%E2%80%93build)

- Failure of the design team to be current with construction costs, and any potential cost increases during the design phase could cause project delays if the construction documents must be redone to reduce costs.
- Redesign expense can be disputed should the architect's contract not specifically address the issue of revisions required to reduce costs. Note: For the majority of bridge replacements no architect is involved.
- Development of a "cheaper is better" mentality amongst the general contractors bidding the project so there is the tendency to seek out the lowest cost sub-contractors in a given market. In strong markets, general contractors will be able to be selective about which projects to bid, but in lean times, the desire for work usually forces the low bidder of each trade to be selected. This usually results in increased risk (for the general contractor) but can also compromise the quality of construction. In the extreme, it can lead to serious disputes involving quality of the final product, or bankruptcy of a sub-contractor who was on the brink of insolvency desperate for work. However, close supervision by the consultant must be performed to ensure proper execution and ensure the required and requested quality.
- As the general contractor is brought to the team post design, there is little opportunity for input on effective alternates being presented.
- Pressures may be exerted on the design and construction teams due to competing interests (e.g., economy versus acceptable quality), which may lead to disputes between the owner and the general contractor, and associated delays in construction.

Advantages (http://en.wikipedia.org/wiki/Design%E2%80%93bid%E2%80%93build)

- The design team is impartial and looks out for the interests of the owner.
- A solution which can safely be executed within the allowed track possession is ensured.
- The design team prepares documents on which all general contractors place bids. With this in mind, the "cheaper is better" argument is rendered invalid since the bids are based on complete documents. Incomplete, incorrect or missed items are usually discovered and addressed during the bid process in the form of addenda.
- Ensures fairness to potential bidders and improves decision making by the owner by providing a range of potential options. It also identifies new potential contractors.
- The IM usually make tender documents for the design projects to ensure that the best and cheapest consultants get the assignment.
- Ensures competition between consultants since tenders often value both cost, qualifications and solution. Therefore, the ideas to reduce track possession and cost are promoted.
- Assists the owner in establishing reasonable prices for the project.
- May use competition in the selection of the contractor to improve the efficiency and quality for owners.
- The design team (consultant and IM) will focus not only on initial design but also on minimizing future O&M cost and minimizing future track possessions. This e.g. by making it easier and faster to replace parts – or improve the quality or amount of renewal to ensure e.g. 25 or 50 years without the need for longer track possessions.
- The regulatory procedures regarding Common Safety Methods on infrastructure projects (CSM-RA), see e.g. EC 352 (2009) and ORR (2012a), and ERA Technical Specification for Interoperability (TSI) are handled effectively during the design phase

and followed during the execution. This is handled by the IM with assistance from the consultant(s).

Design & build (D-B) (based on http://en.wikipedia.org/wiki/Design%E2%80%93build)

Design & build is a project delivery system used in the construction industry. It is a method to deliver a project in which the design and construction services are contracted by a single entity known as the design–builder or design–build contractor. In contrast to "design–bid–build" (or "design–tender"), design–build relies on a single point of responsibility contract and is used to minimize risks for the project owner and to reduce the delivery schedule by overlapping the design phase and construction phase of a project. "D-B with its single point responsibility carries the clearest contractual remedies for the clients because the D-B contractor will be responsible for all of the work on the project, regardless of the nature of the fault".

Disadvantages:

- Limits the clients' involvement in the design
- Difficult selection of contractor: evaluation criteria hardly to justify
- No comparison of project cost possible.
- Contractors often make design decisions outside their area of expertise.
- A designer—rather than a construction professional—is a better advocate for the client or project owner and/or that by representing different perspectives and remaining in their separate spheres, designers and builders ultimately create better buildings. However, within rail bridges a great deal of conservatism is needed in order to adhere to rules, regulations and traditions. Therefore, within structures designers and builders may not always create the better solutions.
- Due to the often tight time schedule the regulatory procedures regarding Common Safety Methods on infrastructure projects (CSM-RA), see e.g. EC 352 (2009) and ORR (2012a), and ERA Technical Specification for Interoperability (TSI) is not handled effectively by the contractor. Additionally, these areas may be associated with high and variable cost which the contractor must include in the bidding.

Advantages

- General contractor is involved in design, input on effective alternates possible- achieves innovation
- Design–build places the responsibility for design errors and omissions on the design–builder, relieving the owner of major legal and managerial responsibilities. The burden for these costs and associated risks are transferred to the design–build team.
- Design–build allows owners to avoid being placed directly between the architect/engineer and the contractor. Under design–bid–build, the owner takes on significant risks because of that position.
- design–build saves time and money for the owner,

The cost and schedule reduction and decreased litigation associated with design–build project delivery have been demonstrated repeatedly. Research comparing US and UK practice showed that design–build projects are constructed faster and more cheaply than design-bid-build projects (Sanvido and Konchar 1999).

However, final quality in design-build projects are often not as high as in design-bid-build projects and often future operation and maintenance cost are not part of evaluation of tenderers and often not the most important issue for the design-build contractor. Therefore, initially design-bid projects may be cheaper than design-bid-build projects but lifetime cost will be higher – and often be associated with longer track possessions.

An example of a traditional procurement method is given in Appendix A.

5.3 Replacement of the superstructure for short spans

5.3.1 General

Often replacement of the superstructure is sufficient if the substructure is confirmed as adequate. As many railway bridges are single span structures, this is an easy and fast way to improve the structural capacity and thus the route availability. The abutments are kept in service and the superstructure is designed to carry the new load.

The procedure consists of at least two stages:

(1) removal of the old superstructure and

(2) placing of the new superstructure.

The new structure can be heavier, i.e. steel beams are changed for a composite steel RC structure where the existing substructure is deemed capable of withstanding increased permanent load.

It is important to make sure that the existing bridge can be moved and is not locked in place due to natural bonding of materials over time and/or due to temporary fixings left in place or permanent fastenings. Good and qualified pre-planning and site visits will pay back.

For bridges with bearings, bearing replacement can be undertaken as an activity within the possession by using precast concrete bearing units bedded and fixed onto the existing substructure. Another alternative is to use some kind of concrete casting. However, castings take some time for hardening which cannot usually be allowed during the possession. For this reason the bridge needs some temporary supports. The superstructure, especially steel beams, must be prepared for two or three points for supports for each bearing. Typically three bearing points are needed, one for the temporary support, one for the final support, and one for lifting of the bridge upon removal of the temporary support. However, it is possible to use just two. If the temporary support is made from a box filled with sand it can just be removed when the final support is ready. The sand must be well annealed to make a stiff support yet easy to remove. An advantage with additional lifting points is that future bearing replacements are simplified

Usually smaller superstructures can be replaced in a 12 hour possession. Different methods for superstructure replacement are described below. One needs to decide whichever is best according to local boundaries. It is often favourable to lift the old bridge out and the new bridge in using a crane if so is possible.

Combinations of the methods are often needed in more difficult projects.

5.3.2 Mobile Crane

Mobile cranes can be successfully used for replacement of the superstructure of bridges. In certain cases it can also be economic to replace bridges by crane for bridges with spans up to 35 m. One requirement is obviously that the crane has the possibility to travel to the bridge site. If the bridge is situated on agricultural land with weak soil this may be a problem. Lifting by crane requires that the old bridge is completely free to move.

One disadvantage with cranes is that overhead cables and equipment must be removed during the work. The crane itself is a very important component in the work; however it is difficult to repair the crane if something unexpected occurs (e.g. overloading, adverse weather conditions such as high wind) and high demands on redundancy may increase costs significantly.

5.3.3 Rail mounted crane

There are also cranes made for transportation along the track, although their lifting capacity perpendicular to the track sometimes is limited compared to mobile cranes. With respect to neighbouring bridges/tracks and the lifting capacity of available cranes in combination with bridge weight, careful planning is necessary.

In the UK rail mounted Kirow cranes are regularly used. One example is the replacement of Pouparts Bridge 18 in London over the Christmas period in December 2010, Poupart (2011). 200 men worked around the clock to replace the 120 year old bridge. The bridge is a 'rail over rail' bridge which carries strategic lines between Clapham Junction and Victoria. With limited access for engineering work and maintenance, it took 12 months of intensive organising and logistical planning to ensure a successful project,

Along the route from the construction site to the bridges site not only the loading capacity has to be considered but also the available clearance.

5.3.4 Rail mounted bridge carrier

One of the most successful methods that has been used over a long period of time in some countries in Europe is the use of a railway bridge carrier. This carrier is mainly a high built railway wagon with plenty of space between bogies and hydraulics for lifting and lowering. An ordinary bridge can be replaced with a possession time of only 12-16 hours.

The wagon itself is not motorized for transport. A locomotive is used to tow the wagon. The new superstructure is constructed in a suitable area, preferable not more than 15 km away from the bridge site. Travelling with a bridge loaded is done at a speed of approximately 10 km/h.

A replacement is illustrated in Figure 5.1. The railway bridge carrier travels to the bridge site with the new bridge loaded. The engine and first bogie of the wagon go over the bridge. The new bridge is turned 90 degrees and the old bridge is lifted and then also turned 90 degrees. The old bridge is lifted and the new bridge is lowered so it can be turned into position. Finally the new bridge is placed on supports and the old bridge can be transported away with the railway bridge carrier over the new bridge. The old bridge will in many cases be sent for recycling and may therefore be cut into pieces.

This procedure is only possible for lighter bridges, i.e. steel beams without concrete or shorter concrete bridges. Turning of heavier bridges cannot be done safely. Concrete bridges may be shifted up to 12 m length. In that case, both bridges will fit without turning.

The railway bridge carrier is transported longer distances in pieces on railway or on lorries. The longest and heaviest part is 20 m with a weight of 20 tons. Assembly and loading of the new bridge takes one to two days with a use of a small crane in combination with lateral move of the bridge. Dismount will also take one day.

(a) The bridge carrier has transported the new bridge into position

(b) The new bridge is turned 90 degrees

(c) The old bridge is lifted and then turned 90 degrees

(d) The new bridge is turned back and lowered into position. The old bridge can then be turned back and transported away

Figure 5-2 A bridge swap with a rail carrier. ML-D3.1 (2013)

The footpath on the side of the bridges must in the case of overhead cables be installed at the site otherwise the bridge will be too wide with respect to trackside structures such as overhead cable supports. Normally, the footpath is bolted to the bridge with prepared fittings. Normally, the ballast is placed on the bridge when it is in place. There is one exception and that is prestressed concrete bridges that often need to be loaded to a certain degree to avoid that the bridge is damaged during lifting.

The new bridge is required to be designed for temporary handling/lifting actions which may be as critical as permanent and transient actions once installed. Larger bridges need a hole in the mid part to allow for lifting equipment of the old bridge. The drainage hole in the new bridge is used for lifting and need to be designed for proper forces.

5.3.5 Longitudinal launching

For longer bridges a railway bridge carrier is not possible to be used. Then a possibility is to connect the old bridge to the new bridge to form one unit and this unit is then longitudinally moved. Once in the right place the bridges are separated and the new bridge is lowered into position.

Temporary mid-point support is often used for longitudinal launching. In such cases hydraulic towers can be used to lift the bridge and transport it away. One way to avoid new mid supports that has been used in some countries is to lift the old bridge, connect it to the new bridge and use the old bridge as a launching beam when the new bridge is launched in place.

5.3.6 Horizontal launching

This method is presented in the Section 5.4.3 for full replacement but can be used also for superstructure replacement

To move a bridge sideways is a rather straight forward procedure and well proven to work. It can be done by placing steel beams on the ground to make a track for temporary roller bearings which are placed under the bridge. A bridge can therefore be built aside the track and then slid into position during a rather short railway possession. In most cases some temporary supports are needed for construction of the new bridge and for a place for the old bridge when it is going to be demolished. By removing footpaths, temporary supports and sliding distance can be minimized.

When a multi-line structure is to be replaced, the work is constrained by the presence of adjacent lines and construction methods become increasingly complex.

Typically, the weight of the bridge will exceed the load capacity available for cranes using the road beside the bridge, while lifting of the bridges over neighbouring active tracks with overhead line equipment (OHLE) is not an option. Other common restrictions on rail mounted cranes include load limits on the adjacent existing abutments.

One of the few remaining construction techniques involves near site fabrication of the bridges and subsequent transportation to the site and launching into their permanent position using multi wheel bridge carriers. This has e.g. been used at the Caversham Bridge Replacement in England, Caversham Bridge (2011). The old bridge can then be towed away using the transporters or track-mounted equipment.

5.3.7 Replacement of decking systems

For a large number of beam or truss bridges it can be sufficient to replace the old decking systems.

A partial replacement for the superstructure for an old truss bridge is an economic decision to prolong service life of the whole structure. Usually three critical constraints are present: (1) working with short possession times; (2) limited substructure capacity; and (3) limited budget. An example of such a replacement is the exchange of the steel truss deck of the arch bridge at Forsmo over the Angerman River in Northern Sweden; see Figure 5.3 Collin et al (2010).

Figure 5-3 Steel truss arch with replacement of top structure (Forsmo bridge over Ångerman River Sweden), Collin et al (2010).

To enable a bridge to resist higher axle loads and prepare it for future traffic, old timber decks can be replaced by a new decking system. The self-weight of the old structure is very low and a lightweight construction for re-decking is often necessary. Here generally two materials can be considered FRP and lightweight concrete. In principle a number of deck units are prefabricated, transported to the site and installed by crane either from the adjacent track or with a mobile crane.

The combination of these constraints, together with a requirement for derailment capacity, limits the available options for the use of FRP composites. Structural options are given in ML-D3.2 (2014) and a first application of FRP railway decking for full derailment capacity is shown in its Annex 1 for the case study “Calder Viaduct Redecking”.

Deck Replacement of High Performance Concrete (HPF) is under development, see ML-D3.2 (2014) and Brûhwiler (2014).

5.3.8 Recommendations

In this section some recommendations will be summarized for replacement of superstructures.
First some important parameters will be presented:

Bridge length

In general one can say: the shorter the bridge, the easier it is to replace it. This is mainly due to the weight of the structure and the many possible ways to transport a light bridge to a construction site. The larger the bridge becomes, the heavier the weight and the fewer the techniques of transport and lifting.

Here a division is made between:

- short bridges, with spans up to 5 m,
- medium bridges with spans from 5 to 20 m, and
- long bridges with spans longer than 20m.

Bridge type to be exchanged

When planning replacement activities, the knowledge of the type of bridge which is to be exchanged is of importance. This way one can already learn about the site conditions and surroundings.

The most common types are:

- Reinforced concrete frame bridges
- Prefabricated reinforced concrete frame bridges
- Culverts and short span bridges
- Steel trusses
- Steel beam bridges
- Arches

There are also many other types, see e.g. SB-LRA (2007). In the planning process the bridge type and the static system are important. This is especially the case when only parts of the superstructure are going to be replaced.

Track possession time

In many countries the track possession time is the factor that has the biggest importance on the choice of methods for replacement. It is also the factor that makes railway bridges more difficult to exchange than road bridges.

For evaluations in this report we differentiate between the following possession times:

- 6 - 12 h
- 12 - 24 h
- 24 - 60 h
- More than 60 h

Some examples of costs associated with different possession times are given above in Section 4.2 and in Appendix C.

Available funding

The available funding is of importance when you are choosing a replacement method. Here we differentiate between

- very restricted funding
- normal funding
- high replacement funding

The importance of the line and the cost of delays may have influence on available funding

Type of crossing and available working site

For the logistics and planning of the construction process the knowledge of the surroundings of the bridge and the use of the bridge is of importance. We differentiate between bridges that:

- run over water
- a rural route
- a highway
- a street in a city
- agricultural land

In all these cases the place next to the bridge strongly influences the construction method.

Regarding available working site we differentiate between

- small sites and
- normal sites

Electrified line

It is easier to exchange a bridge if the line is not electrified as all cables have to be protected so that they are not harmed. This hampers the use of cranes and other equipment. Moreover special measures to work in an electric environment and a more detailed track closure planning and safety management is needed.

Availability of equipment

The availability of equipment is important for the choice of the construction technique. If mobile cranes are available it is much easier to exchange a bridge than if they are not. Railway bridge carriers are not available all over Europe and the same is valid for huge cranes and certain track renewal machinery.

Recommendations for Bridge Replacements

A summary is given of recommendations for available methods for bridge superstructure replacement in Table 5.1.

Before a replacement takes place, the Life Cycle Costs for a replacement should be compared with the costs for strengthening the existing bridge, see ML-D1.4 (2014) and ML-D5.7 (2014). Sometimes the launching of a new bridge (with a short possession time) is more economic than a repair/strengthening procedure but very often the opposite is true.

++ = yes + = may work — = no	Mobile Cranes	Rail Mounted Crane	Rail Mounted Bridge Carrier	Longitudinal Launching	Horizontal Launching	Deck Replacement
1. Bridge length						
1.1 Less than 5 m	++	++	++	++	++	++
1.2 5-20 m	++	++	++	++	++	++
1.3 More than 20 m	+	+	+	+	++	++
2. Bridge type to be exchanged						
2.1 Reinforced concrete beam bridge	+	+	++	++	++	++
2.2 Steel truss	++	++	+	++	++	++
2.3 Steel beam	++	++	++	++	++	++
2.4 Arch	+	+	+	+	+	+
2.5 Other	+	+	+	+	+	+
3. Track possession time						
3.1 Between 6-12 h	+	+	+	-	+	+
3.2 Between 12-24 h	++	++	++	+	++	+
3.3 Between 24-60 h	++	++	++	++	++	++
3.4 More than 60 h	++	++	++	++	++	++
4. Available funding						
4.1 Very restricted funding	+	+	+	+	++	++
4.2 Normal funding	++	++	++	++	++	++
4.3 Money is not the problem	++	++	++	++	++	++
6. The bridge runs over						
6.1 Water	++	++	++	++	+	++
6.2 A rural route	++	++	++	++	++	++
6.3 A highway	++	++	++	++	++	++
6.4 A street in a city	++	++	++	++	++	++
6.5 Agricultural land	+	++	++	++	++	++
7. Available working site						
7.1 Small	++	++	++	+	+	+
7.2 Normal	++	++	++	++	++	++
8. Electrified line						
8.1 Electrified line	+	++	++	+	++	+
8.2 No electricity	++	++	++	++	++	++

Table 5-1 Recommendations for methods for replacement of the superstructure of short span bridges

5.4 Methods for full replacement of bridges

5.4.1 Temporary bridge

A temporary bridge is a structure which is placed under the tracks of the bridge to be changed. The construction work is then carried out under this temporary support.

A temporary bridge can be used when the headroom underneath the track allows reducing the construction height of the new bridge. An example of a cross section is given in Figure 5.4.

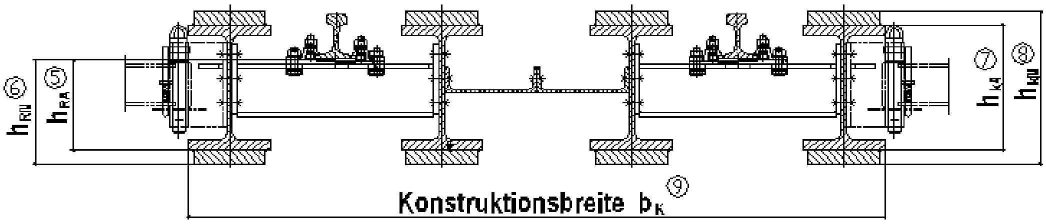

Figure 5-4 Cross Section of a Temporary Bridge used by DB. From ML-D3.1 (2013)

A view of the so called “active rails” before being installed as a temporary bridge is given in Figure 5.5.

Figure 5-5 Active rails to be installed as a Temporary Bridge. From ML-D3.1 (2013)

A temporary bridge can be used several times and is easy to install and remove. Often different lengths are available for spans from 6 m to 24 m. A temporary bridge can be placed on sheet pile walls which are installed in the track. For the temporary bridges used and designed within DB, the allowable train speed is up to 120 km/h in straight tracks and 90 km/h in curves.

Whenever temporary bridges are in use, the loading history should be noted, so that any fatigue problems might be foreseen.

After instalment of the temporary bridge with no ballast and very low structural height, the old bridge is demounted and the new bridge is built underneath the temporary bridge. Old bridges often have large amounts of ballast, which makes it easy to fit the temporary bridge.

More information on temporary bridges is given by Pfeifer & Mölter (2008). A case study is reported in Annex 1 of ML-D3.1 (2013)

5.4.2 Prefabricated elements

Replacing smaller bridges with spans typically less than 5 m is usually done with prefabricated elements. The method has been used extensively the last 10 years and can be executed relatively fast. An example is given in Figure 5.6.

After the track has been closed and the rails removed, the existing structure is removed, improvements to the foundation are made, the prefabricated elements (normally in the form of U-shaped elements) are lifted into place. Waterproofing on the sides of the elements are either rolled or glued to the structure, whereas waterproofing on the top of the elements is normal bituminous waterproofing membrane put on the elements before placing them in the final location. In addition, a layer of concrete (and - sometimes- a steel plate) is put on top of the bridge. This way the bridge deck has an additional coverage to avoid defects caused by tamping. Finally, backfill and drainage is added and track is restored.

This technique can often be accomplished in 24 hours or in a weekend (Friday to Monday morning), but sometimes 6-8 days is needed including removal and replacement of tracks. depending on the geotechnical conditions on site.

The same design life is expected as for in-situ cast concrete structures. The backfill in the transition zone requires additional compacting and track adjustment in the period after replacement.

For some current types of bridges there are standard types available for different countries, see Appendix B. Some examples of production methods for standard bridges are also given in ML-D3.2 (2014). It may be a good idea to further develop designs based on the Eurocodes that can be used in different countries in Europe. An attempt to create such an example is presented in Appendix B.1 and shows the advantages of a general approach.

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(a) Demolition of existing bridge (two track suburban line)

(b) Earthwork before lifting new elements into position

c) Elements are lifted in position

(c) Elements are assembled and waterproofing is added

(e) The new elements in position after about two hours

(f) Concrete is added on top of elements

(g) Track is restored and the new bridge is finished

Figure 5-6 Small underpass built with prefabricated elements in Denmark. From ML-D3.1 (2013)

5.4.3 Horizontal launching

When the bridge to be replaced becomes longer than 15 – 20 m, so that prefabricated elements are no longer an option, the normal procedure is to build an in-situ cast bridge next to the bridge to be replaced. The bridge is completed as much as possible - usually including track and waterproofing. When the new bridge is completed, the track is removed, the old bridge demolished and the new bridge launched horizontally into permanent position, see Figure 5.7.

Before the launching the ground must be prepared for both the new bridge and for the launching beams. However, usually the launching beams can be supported by direct foundation and requires no pile foundation or other permanent structures.

This method requires that the road passing under the bridge may be closed for a couple of months while the new bridge is constructed. In the UK the maximum length of available road closure is usually 6 weeks but in other countries longer times may be available.

It is possible to construct the new bridge next to the road passing under the bridge. However, launching in two directions is more costly - and still requires that the road is closed when the bridge is moved to the permanent position.

5.4.4 Vertical and horizontal launching

When it is not possible to close the road below the bridge for an extended time, it may be possible to build the new bridge at an elevated level next to the permanent position. This means that traffic under the bridge can be maintained - the road needs only to be closed when the new bridge has to be moved into its final location. The method is similar to the previous launching methods with the exception that the new bridge is constructed e.g. 2 m higher than its final location. This means that traffic can be maintained on the road below - however usually with restrictions to the number of lanes and speed in order to protect the building site and ensure the available space around the new bridge. When the new bridge is completed, the existing track is removed; ground works prepared and launching beams are installed. Usually multi wheel bridge carriers or moving hydraulic towers are used, since these may move horizontally and lower the bridge in steps with temporary supports.

(a) Ground is prepared and launching beams are installed

(b) Hydraulic jacks are installed on launching beams. The bridge is lifted 5 cm and moved into permanent position

(c) The bridge has been launched into its final position

Figure 5-7 Horizontal launching of bridge in Denmark. From ML-D1.3 (2013)

5.4.5 Replacement of culverts and small span bridges

Old culverts or small span bridges can be replaced by new ones made of concrete elements, see e.g. Figure 5.8, ML-D1.1 (2013). Culverts with diameters smaller than ~ 1m can be pushed through the embankment without closing the line, while for larger ones the embankment has to be dug out.

Figure 5-8 Concrete culvert made by elements that are locked together by special extending parts from the upper arch elements fitting into recesses in the bottom slab elements. Every upper arch element ties two slab elements together and vice versa. The elements are produced with spans from 0,6 m to 2,5 m. ML-D1.1 (2013).

Metal flexible type of culverts (which can essentially be considered as relatively flexible arch bridges) are getting more and more popular in recent years because they are economical and have shorter construction periods compared to traditional materials/structural types, see Figure 5.9. The components of metal culverts comprise corrugated steel pipe or metal plates with bolted connections and engineered soil backfill. The culverts typically have 3 to12 m long spans.

The performance is governed by soil-structure interaction. The methods of construction are as crucial as the design. The design requires several geotechnical aspects such as bearing capacity of the foundation, long term settlements, interaction between the backfill soil and the structure wall and arching in the soil due to settlements and deformation of the structure. Having low flexural stiffness makes metal arched culverts quite vulnerable during backfilling stages. More detailed information on soil-steel interaction can be found in Pettersson (2007). Culverts made of corrugated steel may have problems with corrosion and life length and this has to be taken into account when this alternative is considered. There have e.g. been problems in the UK with this kind of bridge in areas where streams/rivers have a heavy sediment load. In these cases the service life has been severely reduced due to abrasion wearing away the corrugated metal structure and causing premature failure.

As an alternative to steel plates concrete elements joined together with prestressing is developed at the Technical University in Denmark, Hertz & Halding (2014). Arch vaults are here constructed from equal plane prefabricated light deck

elements, which are assembled on the erection site by means of post-tensioning and lifted in place.

Figure 5-9 Two corrugated flexible culverts (or arch bridges) beside each other are used to carry a two track railway line over a road and a foot-path in Poznan, Poland. Petterson (2007).

Precast concrete arch bridges

There are a number of proprietary precast concrete arch systems available, most of which are intended for use as highway bridges, but which could be used for new or replacement railway bridges if subjected to design verification. These are briefly described below.

Matiere

This comprises a family of designs with differing span capabilities as shown in Figure 5.10. The single element CM2 is suitable for spans between 1.5m and 3m; the double element CM3 for spans between 33m and 8m and the three element CM4 system for spans between 2.5m and 20m. The CM4 system has two variations, the closed cell and open cell.

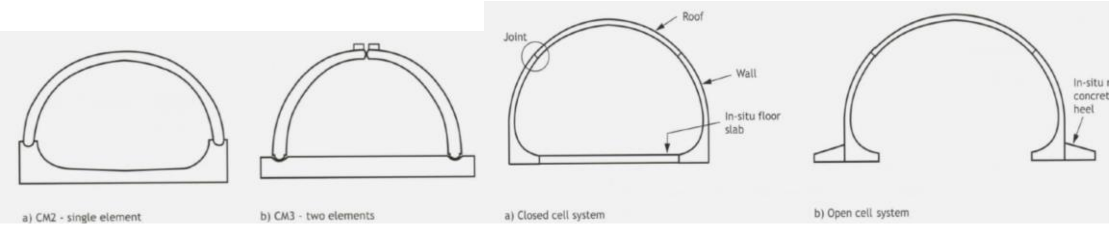

Figure 5-10 The family of Matiere arches (CBDG 2009)

Installation of the CM4 system involves placing the wall sections on pre-prepared foundations before lifting the crown onto the walls, which are designed to be stable without any additional external support. (CBDG 2009)

Figure 5-11 A Matiere arch bridge in Bulgaria

(http://www.abmeurope.com/gallery/civil-engineering**)**

Techspan

The Techspan system is suitable for spans of up to 20m and is made up of three main components; the foundations, the arch segments and the crown beam as illustrated in figure 5.12. As the arch units are not self-supporting they are installed in pairs, staggered longitudinally to provide support for subsequent units. The crown beam can be cast at any time up to the placing of backfill to crown level. (CBDG 2009).

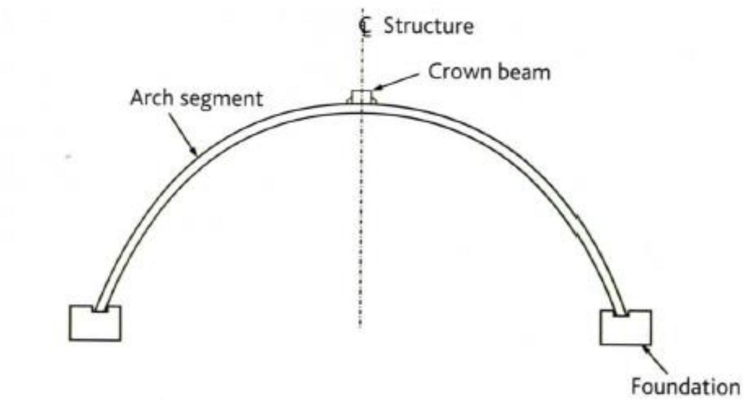

Figure 5-12 The main components of the Techspan arch system (CBDG 2009)

Figure 5-13 Installation of a Techspan arch

(http://img.archiexpo.com/images_ae/photo-g/long-span-reinforced-concrete-arches-precast-units-59280-3617181.jpg)

Figure 5-14 A Techspan arch structure spanning a local railway. (RECo)

BEBO

The BEBO system is based on overfilled reinforced concrete arches and at its core are its precast reinforced concrete arch elements. Three different series have been developed, in order to cover a wide variety of applications:

- E-Series arches can be either single or double leaf having an elliptical shape and cover span ranges from 3.6m to 25.6m
- C-Series arches have a circular shape and are well-suited to carrying high overfills and heavy loads with a span range of 9.1m to 12.8m.
- T-Series arches form a series of flat arches, optimized for shallow overfills up to 1.5m and applications with limited overall structural heights and span ranges from 7m to 31m (BEBO Arch International AG)

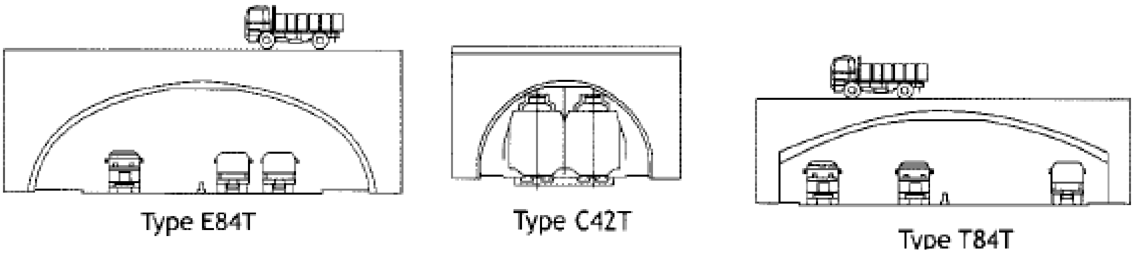

Figure 5-15 The different types of BEBO arch available (Adapted from CBDG 2009)

Figure 5-16 A completed BEBO double leaf C series bridge

(From http://www.beboarch.com/article/artFile/17-111128-Bridges.pdf **)**

Flexiarch

The Flexiarch is a precast system for new build or replacement unreinforced concrete arch bridges. It is delivered to site flat on a lorry or rail wagon and assumes its arch shape during erection as shown in Figure 5.17.

Figure 5-17 A Flexiarch during installation

http://www.macrete.com/flexiarch/downloads

The system can be configured as a semi-circular, segmental or double radius arch, with the double radius being specifically designed for application to bridges spanning railways, where larger clearances are normally required at haunch level. Figure 5.18 shows the comparative profiles of a double radius and segmental Flexiarch of similar spans

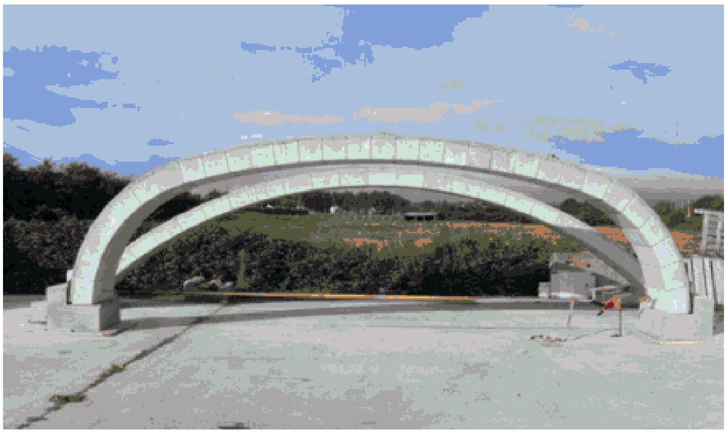

Figure 5-18 Comparative Flexiarch profiles

http://www.macrete.com/flexiarch/downloads

It is also possible to install a Flexiarch without disturbing traffic using the bridge, as illustrated in Figure 5.19, where each separate unit is first erected on an extended abutment outside the bridge and is then jacked along the precast concrete cill beam to its final position.

Figure 5-19 Installation of a Flexiarch by jacking

http://www.macrete.com/flexiarch/flexiarch-projects/ashton-bridge

Network Rail reinforced concrete arch overbridge

Network Rail has developed a standard reinforced concrete arch bridge for bridges crossing the railway. It is suitable for use on both electrified and non-electrified lines and for bridges having spans of 7.4m, 8.4m and 9.4m with skews of 0^o, 15^o, 30^o and 45^o and a width of 4.5m or greater. The minimum construction depth at the crown is 575mm and the minimum road vertical curve radius is 20.6m. (Network Rail 2010)

Figure 5-20 Network Rail reinforced concrete arch overbridge being installed by rail and road cranes

http://www.macrete.com/macrete-projects/railways/egip-walton-road
http://www.macrete.com/macrete-projects/railways/egip-gain-road

Other methods

A new bridge can also be pressed through the railway embankment in the same way as was the method presented for culverts. Examples on how this can be done are given in e.g. Pfeifer and Mölter (2008). The replacement can often be carried out during a 72 hour possession time.

When a new bridge was required to permit a flood relief channel for the river Thames to pass under the Great Western main line near Maidenhead (a 200kph railway) the new bridge was thrust bored through the embankment without any rail closures, Dorney Bridge (2009).

5.4.6 Recommendations

As in section 5.3.8 on recommendations for replacement of bridge superstructures, below parameters for decision making for some suitable methods are presented and explained for the full replacement of bridges. These parameters can be seen as reference points. The factors influence the choice of the replacement method significantly.

Bridge length

In general one can say: the shorter the bridge, the easier it is to replace it. This is mainly due to the weight of the structure and the many possible ways to transport a light bridge to a construction site. The larger the bridge becomes, the heavier the weight and the fewer the techniques of transport and lifting.

Here a division is made between:

- short bridges, with spans up to 5 m,
- medium bridges with spans from 5 to 20 m, and
- long bridges with spans longer than 20m.

Bridge type to be exchanged

When planning replacement activities, the knowledge of the type of bridge which is to be exchanged might be of importance. This will help to consider site circumstances at an early stage of planning. It indicates directly parameters like height constrictions and crossing partners to be considered when replacing the bridge.

The most common types are:

- Reinforced concrete frame bridges
- Prefabricated reinforced concrete frame bridges
- Culverts and small arches
- Steel trusses
- Steel beam bridges
- Arches

There are also many other types, see e.g. SB-LRA (2007). In the planning process the bridge type and the static system are important.

Track possession time

In many countries the track possession time is the factor that has the biggest importance on the choice of methods for replacement. It is also the factor that makes railway bridges more difficult to exchange than road bridges.

For future evaluations in this report we differentiate between the following possession times:

- 6 - 12 h
- 12 - 24 h
- 24 - 60 h
- More than 60 h

Some examples of costs associated with different possession times are given above in Section 4.3 and in Appendix C.

Available funding

The available funding is of importance when you are choosing a replacement method. Here we differentiate between

- very restricted funding
- normal funding
- high replacement funding

High costs may be motivated for a line of high importance with high costs of delays or non-availability.

Geotechnical conditions

Of course the geotechnical conditions are of importance when a bridge shall be exchanged. Here we differentiate between

- good conditions
- normal conditions and
- bad conditions

Here a lot of regional and national differences and variations are possible. A geotechnical report is necessary. For a rough estimation it is in many cases possible to refer to data from the construction activity when the bridge was built – if anything is available. One may do without a geotechnical report if the new deck is not to be heavier than the existing one, and the bridge and its abutments are OK.

Type of crossing and available working site

For the logistics and planning of the construction process the knowledge of the surroundings of the bridge and the use of the bridge is of importance. We differentiate between bridges that:

- run over water
- a rural route
- a highway
- a street in a city
- agricultural land

In all these cases the place next to the bridge strongly influences the construction method.

Regarding available working site we differentiate between:

- small sites and
- normal sites

Electrified line

It is easier to exchange a bridge if the line is not electrified as all cables have to be protected so that they are not harmed. This hampers the use of cranes and other equipment. Moreover special measures to work in an electric environment and a more detailed track closure planning and safety management is needed.

Availability of equipment

The availability of equipment is important for the choice of the construction technique. If mobile cranes are available it is much easier to exchange a bridge than if they are not. Railway bridge carriers are not available all over Europe and the same is valid for huge cranes and certain track renewal machinery.

5.5 Full replacement of long spans

5.5.1 Multispan integral bridges

A general method for full replacement of concrete multispan integral railway bridges is, exemplified in Figure 5.21. This bridge is a common bridge type in Scandinavia although not commonly replaced in an effective way.

Figure 5-21 Multispan integral bridge

The substructure is fixed to the superstructure. The type is divided into integral slab bridge and integral beam bridge where the latter one is used for longer spans. These types of bridges are today typically replaced during long track closures. Here one important prerequisite for the work is that 18 to 24 hours are available without railway traffic.

Preparations

With such short tack possession a large amount of preparing work is needed. Before the track closure the new bridge and the new columns have to be built. New substructure is constructed by installing large diameter steel piles. All work with new substructure can be done under the existing bridge without any disturbance of traffic. The new superstructure can be built in the vicinity of its final position from where it typically will be horizontally launched. The new superstructure can be prepared with ballast before launching or ballast can be added later when the bridge is in place. To be able to launch the old bridge sideways there have to be temporary columns. This implies that temporary supports for both the old bridge and the new bridge are needed, i.e. temporary supports on both sides of the final bridge positions. These temporary supports do however only need to carry the load from the superstructure and not any traffic loads. The temporary supports can be made of crushed rock, timber grillage, concrete blocks, piles or other solutions depending on local conditions. The layout of the construction site depends heavily on local conditions and space available. It is possible to launch the superstructure longitudinally to get in into position before the track possession. If the railway bridge is crossing a road a temporary structure can be used to protect the passing traffic beneath the bridge if the superstructure is built over the road. In Figure 5.22 the new superstructure on temporary columns are shown on the left side. In the middle the existing superstructure is shown and on the right side temporary supports.

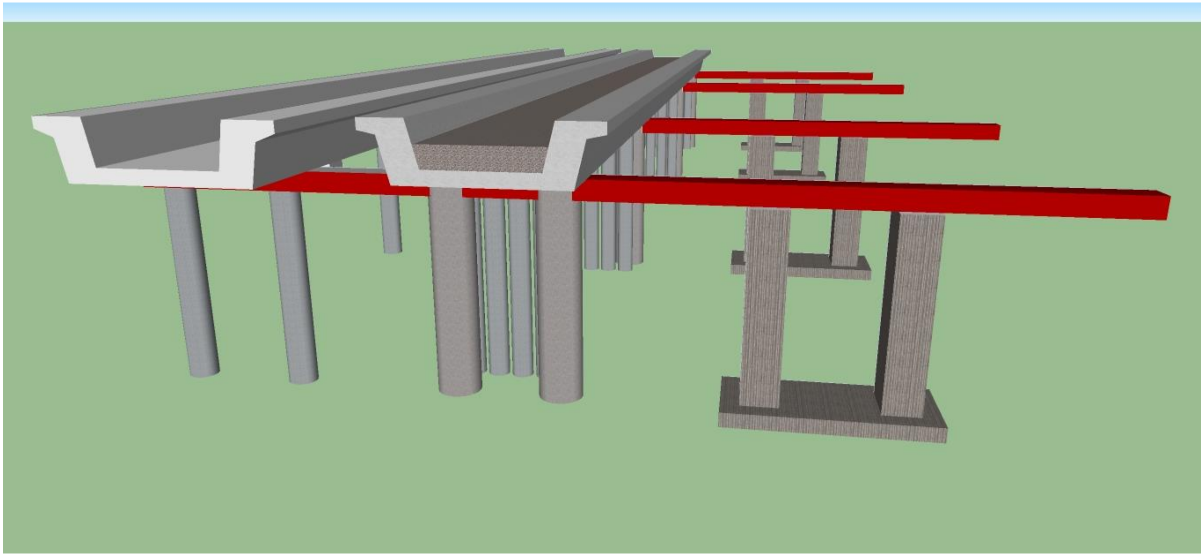

Figure 5-22 Superstructures ready for launching, ML-D3.2 (2014)

Since existing columns are fixed to the superstructure, it is of outmost importance to cut the columns before the track possession starts. Depending on column design, it might be necessary to use some temporary coupling device between columns before cut and track possession starts

Short track possession

As all demolition works are made in the previous step, the work during the track possession will be a rather simple swapping of superstructures. After removal of the already cut track, soil between bridge wings must be excavated. The temporary anchorages that fix the columns to the substructure are released simultaneously with the excavation work.

First, the old superstructure is launched sideways and then the new superstructure is launched in place. Different launching methods are described in ML-D3.2. (2014)

When the new superstructure is placed in its final position sub- and superstructure are connected. The top of the column is welded to prepared plates in the superstructure. The welding can be done simultaneously as track is restored. Some attention must be given to avoid lifting forces when placing ballast if that is not done on beforehand. When welding is finished and track is in place, tamping procedures can be made and track to be opened with reduced speed. Demolition of the old substructures is done after the bridge is in place and track is reopened.

5.5.2 Composite launching nose

This method is developed for replacing longer bridges in areas that are difficult to access or where space is limited. The main idea is that the new bridge is connected with the old bridge to form one unit. The two bridges are launched together. Bridges are separated. The old bridge can be transported away. The method is suitable to use for spans over 25 metres when all work must be done from the track. This solution builds on the concept of using the old bridge superstructure as a type of longitudinal launching. In this way the old superstructure is removed from its current position at the same time as the new get into its final position over the abutments. The launching is right over and parallel to the track. This means minimum additional fill or space around the abutments is needed. The method is further described In ML-D3.2 (2014).

5.5.3 New bridge as crane beam

For longer bridges, i.e. around 30 meter and up, the new superstructure may sometimes be used as a crane beam to facilitate removal of the old superstructure. The new superstructure is constructed elsewhere. When track possession starts the new superstructure is placed on track next to the bridge as shown in Figure 5.23.

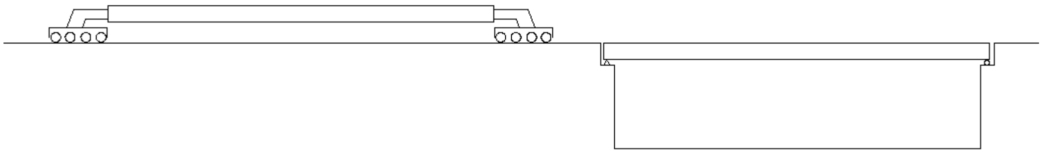

Figure 5-23 New superstructure next to the bridge

The new superstructure in positioned above the bridge and the old superstructure is connected by cables or bars, as shown in Figure 5.24.

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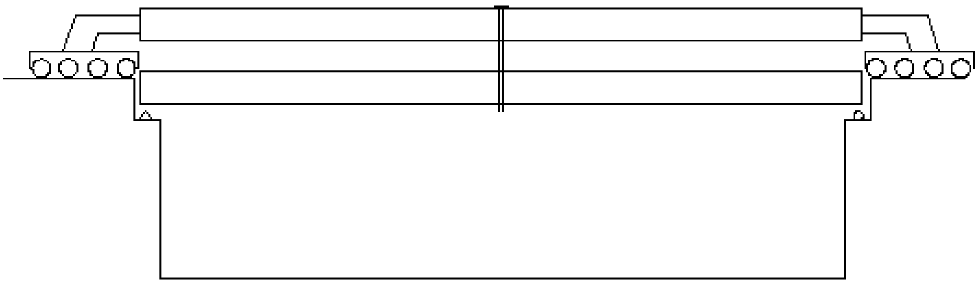


Figure 5-24 New superstructure acts like a crane beam

The old superstructure is lifted from its bearings and is rotated so it can be lowered between the supports, as shown in Figure 5.25.

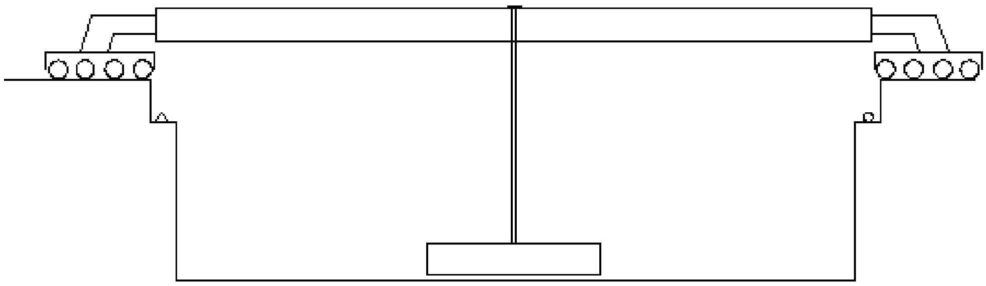


Figure 5-25 Old bridge rotated and lowered

Many different scenarios are possible here. If there is a road under the bridge this must be temporarily closed. The old superstructure is transported away or demolished at site. If there is water underneath the bridge the truck can be replaced with a barge. The water may of course not be big enough for a barge and then the superstructure can be turned less than 90 degrees, just as much to get it away from the supports and lowered to rest on the shore. The superstructure gets cut into smaller pieces and taken away using a crane. The cutting and removal can also be done from the ice if the climate and environment allows for that. Removal of the old bridge however normally takes place after the track is reopened. After the old superstructure has been lowered, the new one is lowered into place, as shown in Figure 5.26. Further recommendations are given in ML-D3.2 (2014).

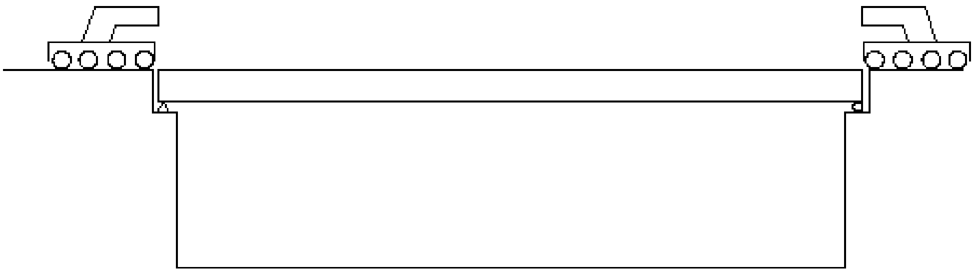


Figure 5-26 The new bridge in place.

5.6 Substructure/Abutments

For small bridges, i.e. bridges without any bearings, it is important to obtain acceptable supports. In many cases where substructure is made of stone, the support can be reused. One well proved method is to place a Styrofoam wall on the front edge and on the sides, and then almost fill the created volume with a grout before placing the superstructure. When the superstructure is lowered it will get in contact with the Styrofoam which then is locked in position. During further lowering the soft Styrofoam will compress and prevent the grout to fall out, instead the grout will level out and be pressed up around the side of the bridge ends.

Sometimes substructures need to be replaced. To construct new substructures in an existing line without disturbing the traffic is a great challenge. A proven method would be underpinning using mini piles or similar or using ground anchors to tie an abutment back into the embankment.

One method possible to use when bedrock is not too deep is steel pipes. Without disturbing traffic, except for shorter stops when establishing machinery, large diameter steel pipes are drilled from surface down to bedrock. Steel pipes with diameter of approximately 800 mm to 1,000 mm are used. These will serve as columns and substructure for the new bridge. Typically four pipes are installed for a small bridge: see ML D3.2 (2014).

For larger bridges there are several possibilities to construct new supports underneath the existing bridge and then just replace the superstructure during a shorter track possession. For some of the old bridges the need for temporary support points has not been foreseen in the design, i.e. rebuilding of the bridge or building new support structures incl. possible strengthening of the existing bridge may be the only option."

It is also possible to make traditional substructures in some cases. However, vibrations from piling or other work must be monitored and controlled. Examples of substructure work are also given in Pfeifer & Mölter (2008).

5.7 Recommendations for Full Bridge Replacements

A summary is given of recommendations for available methods for full bridge replacement in Table 5.2.

Before a replacement takes place, the Life Cycle Costs for a replacement should be compared with the costs for strengthening the existing bridge, see ML-D1.4 (2014) and ML-D5.7 (2014). Sometimes the launching of a new bridge (with a short possession time) is more economic than a repair/strengthening procedure but very often the opposite is true.

++ = yes + = may work – = no	Temporary Bridge	Prefabricated Elements	Horizontal Launching	Vertical and Horizontal Launching	Culverts or Small Spans
1. Bridge length					
1.1 Less than 5 m	++	++	++	++	++
1.2 5-20 m	++	++	++	++	++
1.3 More than 20 m	+	++	++	++	++
2. Bridge type to be exchanged					
2.1 Reinforced concrete frame	++	++	++	++	+
2.2 Prefabricated RC frame	++	++	++	++	+
2.3 Steel truss	-	++	++	++	++
2.4 Steel beam	++	++	++	++	++
2.5 Culver or small span	+	+	+	+	++
2.6 Arch	++	++	+	+	++
2.7 Other	+	+	+	+	+
3 Track possession time					
3.1 Between 6-12 h	++	-	+	-	+
3.2 Between 12-24 h	++	-	++	+	+
3.3 Between 24-60 h	++	+	++	++	+
3.4 More than 60 h	++	++	++	++	++
4. Available funding					
4.1 Very restricted funding	-	+	+	-	++
4.2 Normal funding	+	++	++	++	++
4.3 Money is not the problem	++	++	++	++	++
5. Geotechnical conditions					
5.1 Bad	+	+	+	+	+
5.2 Normal	++	++	++	++	++
5.3 Good	++	++	++	++	++
6. The bridge runs over					
6.1 Water	++	+	+	+	++
6.2 A rural route	++	++	++	++	++
6.3 A highway	++	+	++	++	++
6.4 A street in a city	++	+	+	+	+
6.5 Agricultural land	++	+	+	+	++
7. Available working site					
7.1 Small	++	-	+	+	+
7.2 Normal	++	++	++	++	++
8. Electrified line					
8.1 Electrified line	++	+	++	+	++
8.2 No electricity	++	++	++	++	++
9. Equipment availability					
9.1 Mobile cranes not available	+	-	+	+	+
9.2 Mobile cranes available	++	++	++	++	++

Table 5-2 Recommendations of methods for full replacement of standard bridges

6. Replacement of Track, Switches and Crossings

According Zschoche (2011), Western Europe spent during 2011 around 16 bn € (7,500 million € for maintenance and 8,000 million € on renewal works) to maintain a railway network of around 225,000 km. Urged by these high volumes of investment in combination with the increasing financial pressures to reduce the expenditure of maintenance and renewal (M&R), many IMs around Europe decided to reconsider their existing M&R strategy and develop a new one to meet today's demands of customers, railway operators and governments.

Traditionally, maintenance and renewal works were planned mostly independently, on a time-dependent basis and focused on short payback times on investments and quick performance improvements. However, as it can be shown in the figure below, maintenance strategy (e.g. definition of the intervention level) has a direct effect on the total service life of the track and therefore, on the total cost of ownership. According to Veit (2011), investment delivers just initial quality, while maintenance transforms this initial quality into service life. Therefore, an integrated maintenance and renewal (M&R) approach is mandatory, if a reduction of overall costs is sought.

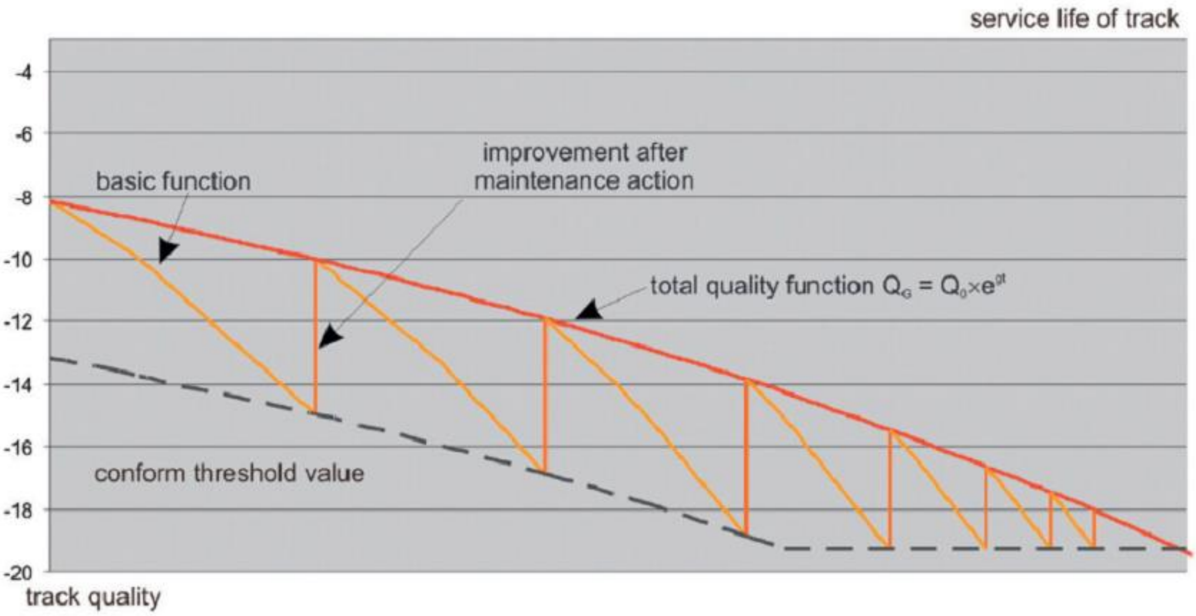


Figure 6-1 Effects of maintenance strategy on track service life Schilder (2013)

The ever-increasing financial pressure on Infrastructure Managers (IMs) to maximize the cost-efficiency of maintenance and investment works has created the need of a more conscious and transparent decision-making processes. For this reason, conventional M&R plans based on the historic knowledge of skilled permanent way engineers are no longer acceptable as the effectiveness of those plans cannot be demonstrated explicitly and the plans cannot be optimized based on performance targets.

The long lifespan of track assets (over 25 years in many cases) emphasises the importance of these M&R plans: an ill thought out maintenance approach can result in backlogs that can lead to progressive degradation and thus premature replacement. As a consequence, life-cycle management approach (LCM) has been adopted by many IMs. By considering the overall lifespan of the assets, the return on investment of different alternatives can be assessed and optimized.

M&R plans may present significant differences between different IMs, although many principles -such as the consideration of overall life cycle costs - are common in all cases. Furthermore, in many cases, the adoption of these new strategies accompanied other improvements in planning, design, execution and control phases that are worthy of description.

This guideline includes a brief review of several integrated M&R strategies adopted by European IMs with the aim of identifying effective decision-making processes and methodologies as well as proven innovations in all project phases that contributed towards an optimisation of overall LCC. After this top-level analysis of M&R strategies, most common as well as best-practice replacing methods for S&C are benchmarked and guidelines are present to help in the decision of the most suitable renewal method.

6.1 Review of integrated M&R strategies

6.1.1 The German 3-i Strategy

With a total track length of 64.113 km and around 70.000 switches and crossings, DB Netz average expense in track maintenance reaches 1.5 bn € per year, while the renewal of track superstructures accounts for 1.2 bn €. Only in 2012, 3.400 km of rail were replaced, as well as 2.4 million of sleepers and 3.7 million tons of ballast, with an overall expenditure of 4.4 M€. These figures are not occasional, but as it can be seen in Figure 6.2, they represent the normal rate of renewal works during the last years Busemann (2009). Taking into account this high rate of renewal works, the development of an efficient track M&R strategy was needed, and hence the “3-i strategy” was developed.

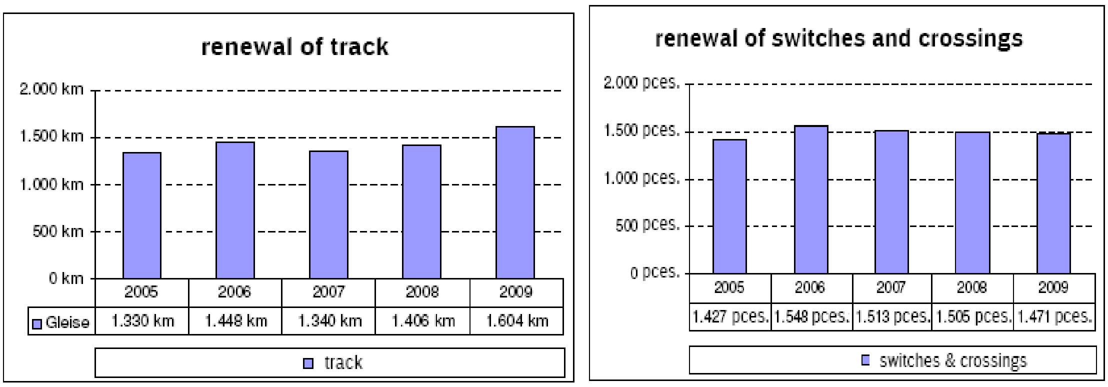


Figure 6-2 Renewal of track and switches and crossing by DB Netz from 2005 to 2009.Busemann (2009).

The name “3-i” is derived from the German for “integrated investment and maintenance strategy” (Integrierte Investitions- und Instandhaltungsstrategie). This strategy was developed in 2006 in the context of the “ProNetz” project and is the basis on which maintenance and renewal works are now organised at the IM. The ultimate goal of the 3-i strategy is the reduction of LCC while offering the maximum possible availability of the network. To achieve this objective, the strategy is based on ten core principles that are related to cost, availability and quality.

- **Integration of M&R**: the integration of M&R planning, design and execution in a technical and economical way is one of the main principles of the 3-i strategy.

- **Categorisation of the network**: In order to facilitate the prioritisation of budget-allocations, the network was divided in four categories according to its importance. This importance is based on the speed, traffic and axle load. Figure 6.3 shows that the main lines (class 1) receive about the 70% of the M&R budget.

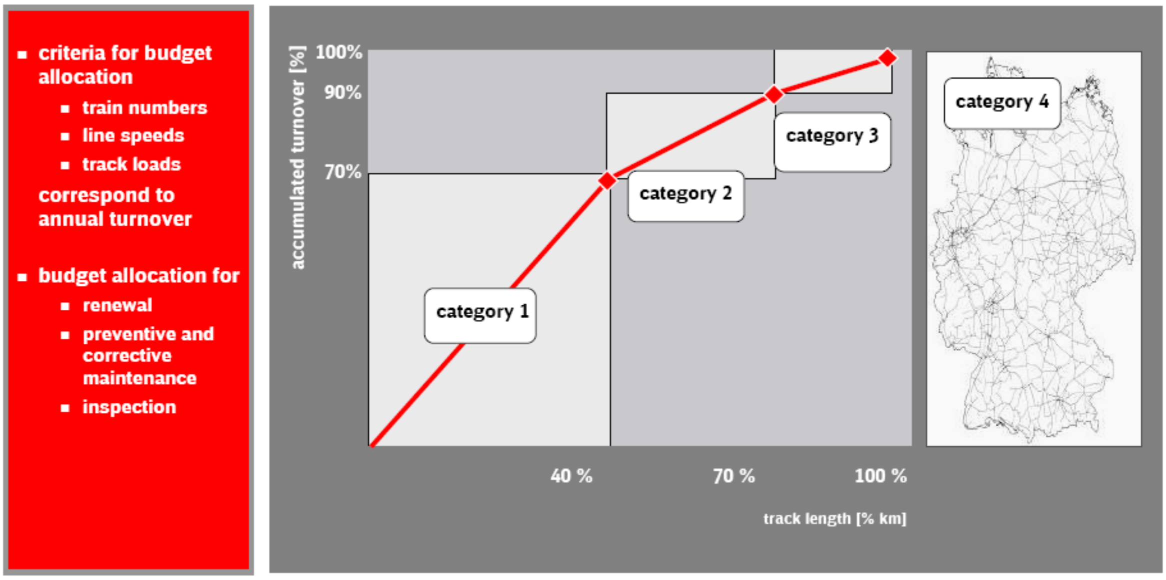


Figure 6-3 Categorisation of the German network according to its importance. Busemann (2009). [3]

- **Definition of "sets of actions"**: a total of 150 maintenance and renewal activities are defined (e.g. rail replacement, tamping, grinding, etc.) in the model, which are also classified according to the "object" groups (e.g. plain track, switches, tunnels).

- The **decisive element in the planning process** is the consideration of **quantity and price**: The output of the planning process is a volume of work for each specific activity (e.g. X km of grinding, Y km of rail renewal, etc.) and its total associated budget. For this reason, the decision-making processes consider these two key parameters as the main elements for the optimization of the M&R strategy.

- **Price definition by cost-metre ratio** for maintenance and renewal activities: The cost of M&R activities is quantified using metric units (i.e. price per m or km). The simplicity of this cost definition has several advantages, such as the facilitation of an easy and quick cost benchmarking of the same activity between regions. In addition, this price is usually associated with a specific quality of work, which is defined by a Service Level Agreement (SLA) signed by the contractor and DB Netz. By doing this, the quality of the executed work can be controlled and guaranteed.

- **Consideration of asset condition**: in order to identify the need of M&R actions, an assessment of existing and future asset condition is required. The Asset Management tool used by DB Netz classifies the network according to six different parameters (age, traffic load, speed, radii, condition key-figure and type of track). From the information obtained through the monitoring of assets, the existing condition of assets can be derived, whilst the future condition of a specific line section is estimated based on historical data relating to the six parameters.

- **Life cycle approach**: considering the whole service life of assets is required, if long-term savings are sought. In combination with historical data on asset condition degradation, the life cycle assessment tools enable the evaluation of different alternatives as well as the identification of cost drivers.

- **Increase (advance) the planning process period**: planning plays a key role in the effectiveness of the M&R strategy (e.g. the bundling of M&R works is only possible if planning process is long enough) but also in the operational hindrances of the M&R works. In this sense, by starting the planning process earlier, a more exact and reliable planning can be done, whilst the operational impact can be reduced.

- **Bundling of activities:** As explained before, the effectiveness of the maintenance and renewal activities and thus, the availability of the network represent also a key element of the 3-i strategy. The concentration of construction and maintenance activities improves considerably the cost-efficiency of the M&R works. As an example, the site length of construction activities increased by 15% from 2005 to 2008. To organize the bundling of construction activities, several “construction site corridors” are defined. As shown in Figure 6.4, by increasing the number of these construction site corridors from 28 to 63, the number of track possessions was significantly increased from 132 in 2007 to 893 in 2008.

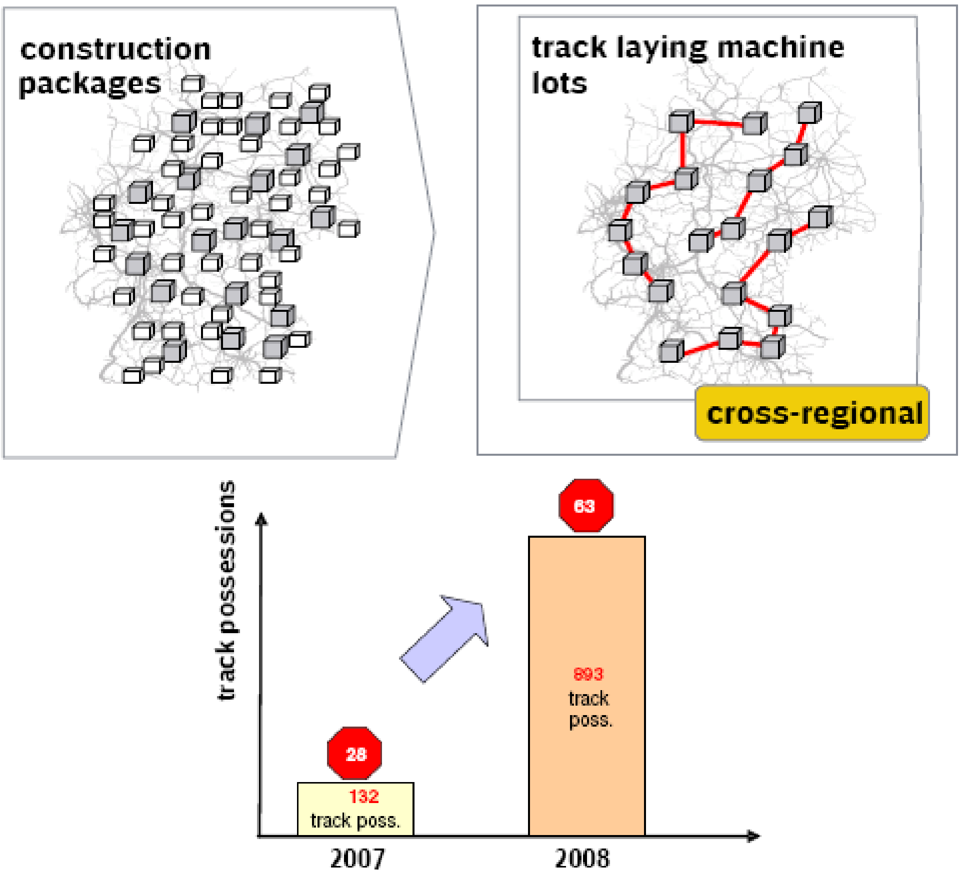


Figure 6-4 Bundling of construction sites. Above: distribution of construction activities in 2007 (left) and 2008 (right). Below: Increase of track possession due to the increase of construction site corridors. Busemann (2009).

- **Integrated top-down and bottom-up approach**: M&R planning follows a coordinated top-down and bottom-up process between the company's central office and regions. The central office determines the actions to be taken, establishes the targets to be achieved and coordinates the resources at a supra-national level. This plan is adjusted by the regional divisions according to their specific needs. Usually, centrally planned actions account for more than the 80% of the total budget. After the implementation of the M&R activities, the information of final prices, tasks outputs, etc. is incorporated in the models developed and managed by DB Netz central office.

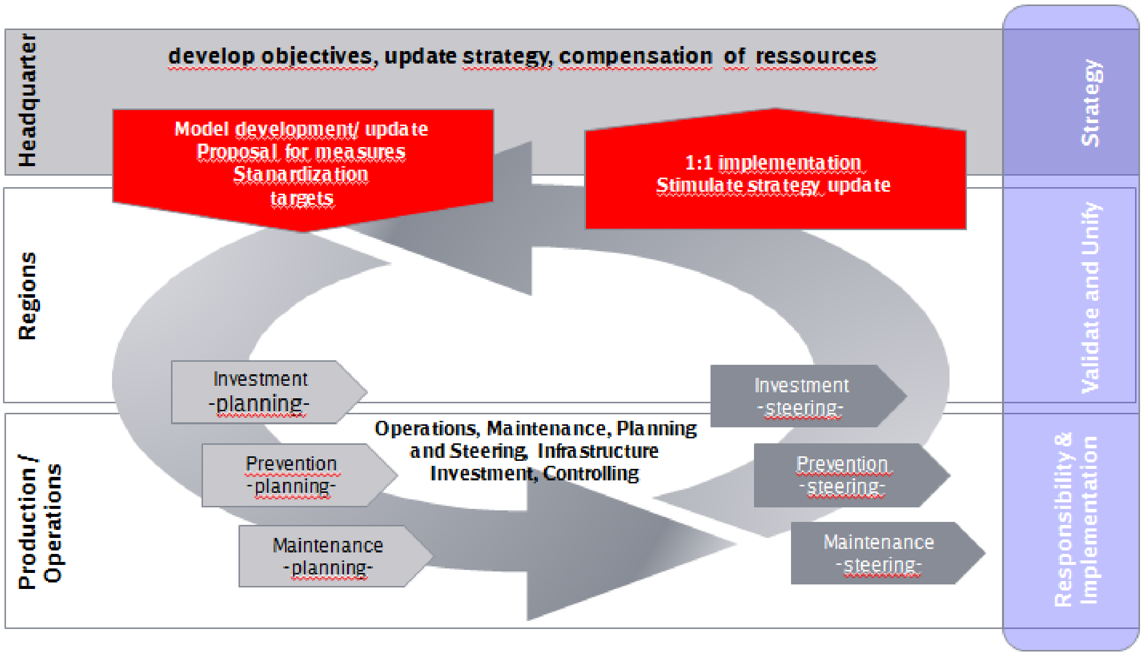


Figure 6-5 Top-down and down-top approach of German 3-i strategy. Siegmund (2013)

As a summary of the strategy, Figure 6.5 is presented, where the workflow of the annual plan for maintenance and renewal is depicted. Firstly, the need of action (i.e. required investments and maintenance) is identified as a result of the analysis of the following inputs: asset condition (e.g. identified faults, age, etc.), line category, list of specific M&R activities and existing regulations/policy. The need of action is also assessed taking into consideration economical, technical and quality aspects. For the elaboration of the preliminary planning, a prioritisation process of the M&R activities identified in the previous step is carried out. This prioritisation of actions is done according to four main factors: Budget (available funding from BHH, regional budget allocation, etc.), Quality (induced delays of M&R activities), Capacity (line capacity planning, logistics, etc.) and Costumers (operating companies, etc.). Once the final planning is established it is communicated to both DB Netz and Costumers (DB corporation, train operating companies, end users, etc.) in order to proceed with the implementation of the planning: definition of the schedule of the works, prepare the tenders to contractors and suppliers, etc.

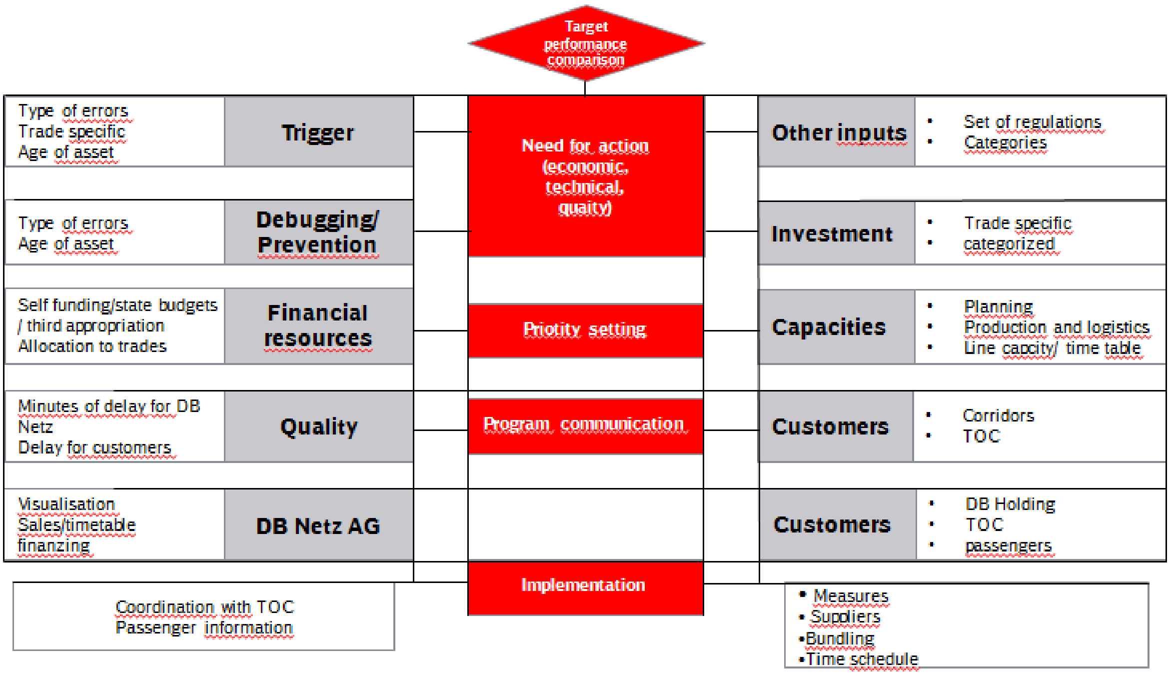


Figure 6-6 Workflow of German 3-i strategy. Gramer (2010)

6.1.2 The Austrian (ÖBB) Strategy

The core element of ÖBB strategy is their comprehensive Life Cycle Management. The new infrastructure strategy model is based on life cycle cost analysis and is linked with new track monitoring equipment and analysing tools. For the implementation of this strategy, an extensive collection of data was required, which started in 2000. The M&R strategy workflow is presented in the Figure 6.7.

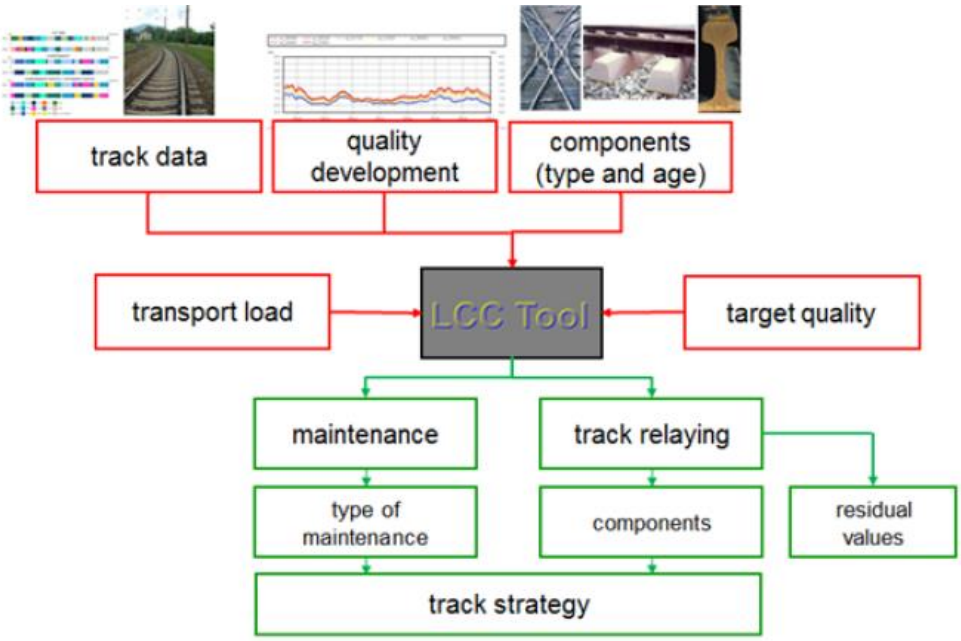


Figure 6-7 M&R strategy workflow of Austrian Federal Railways. Schilder (2013).

NATAS (New Austrian Track Analysing System) was introduced in 2003 to support the planning of track maintenance. This system contains an extensive data base with all the inspection and monitoring information of the network. However, firstly, the network was divided in standard elements (e.g. one km of track or one turnout) and classified according to traffic load, speed, single or double track, type of track, alignment and subsoil condition.

The compilation of track monitoring information has resulted in specific degradation patterns for each type of line section, see Figure 6.8, Schilder (2013). As a consequence, NATAS is able to prognosticate the degradation of track quality, which is a key for the assessment of different strategies in terms of LCC. Initially, the monitoring information gathered referred mainly to a track quality index, but it was later complemented by the registering of specific asset status.

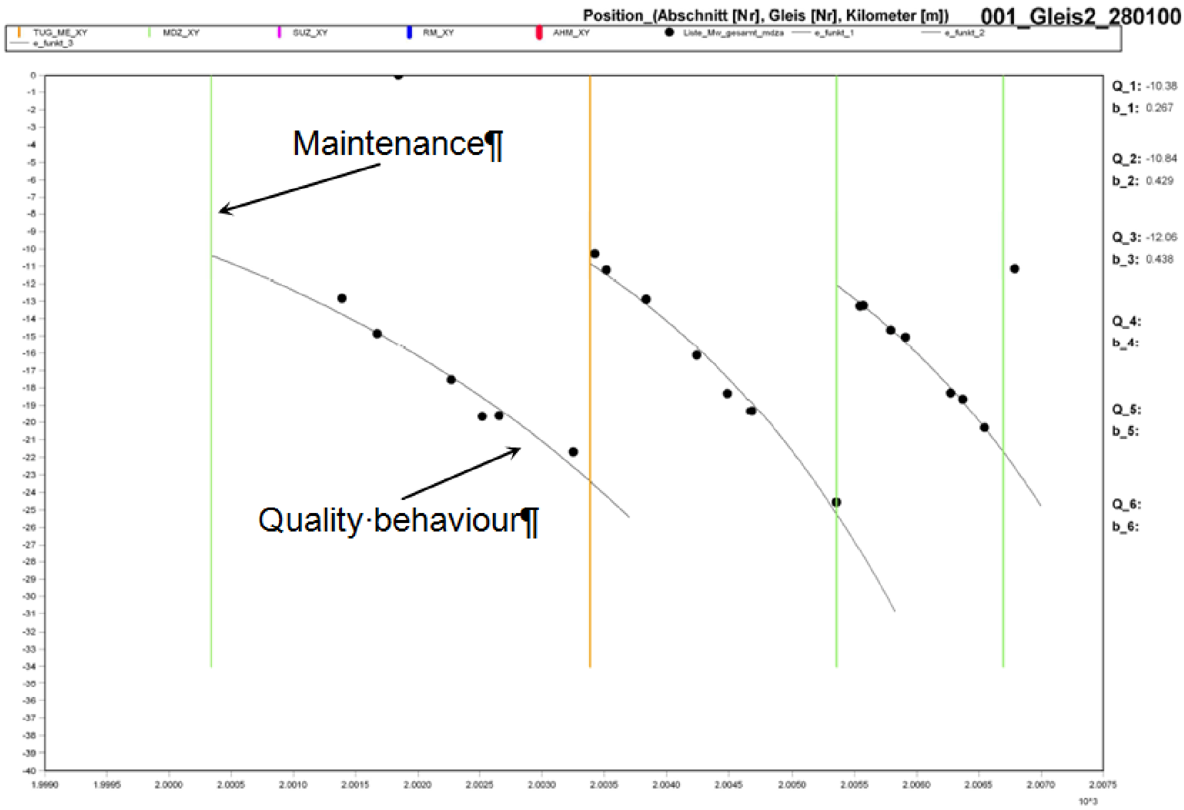


Figure 6-8 Degradation profiles obtained from measured data (track quality). Schilder (2013) [2]

As explained previously, the primary target of the ÖBB Life cycle Management is the support of LCC based strategies in demonstrating its economic benefits. The costs considered in the LCC tool are not only direct costs (inspection, maintenance and investment) but also indirect costs associated with the operational impact (train delay costs, re-routing costs, etc.).

A part from minimizing long-term costs by optimizing maintenance and investment works, ÖBB also seeks a reduction of direct costs by incorporating proven and standardized innovations, such as Under sleeper Pads, USP, and by increasing the efficiency of works.

LCC studies carried out by ÖBB showed that the overall cost of turnouts can be reduced by 13 to 15% if USP are used (Figure 6.9).

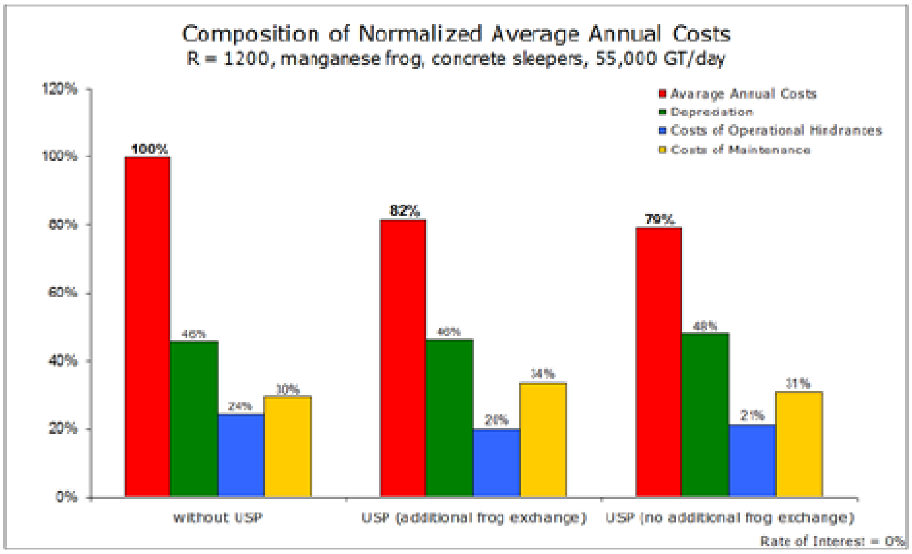


Figure 6-9 Economic efficiency of USP turnout. Schilder (2013).

In what refers to the efficiency increase of maintenance and renewal works, ÖBB employs high capacity machines, which involves in many cases the combination of several machines, such as track relaying and ballast cleaning systems or transport and laying systems for pre-assembled “plug-in” turnouts.

6.1.3 The Dutch (ProRail) Strategy

ProRail is responsible of the construction, maintenance and operation of the Dutch railway network, which is one of the most heavily used and complex mixed traffic railways in Europe. Among the European IMs, ProRail is the only one outsourcing all works (from design to maintenance and renewal, through construction). This particularity implies a well-defined contract policy where defining performance targets is crucial. The measuring and reporting on quality is also outsourced.

Figure 6.10 shows the allocation of funding to M&R activities, Swier (2005). Moreover, it should be said that maintenance of track and turnouts consumes the 50% of the total maintenance budget whilst due to their high cost of installation and rapid deterioration, track and S&C renewal represent 75% of the total renewal costs. Taking this into account, ProRail developed policy plans for track assets and maintenance management, Zoetman (2007).

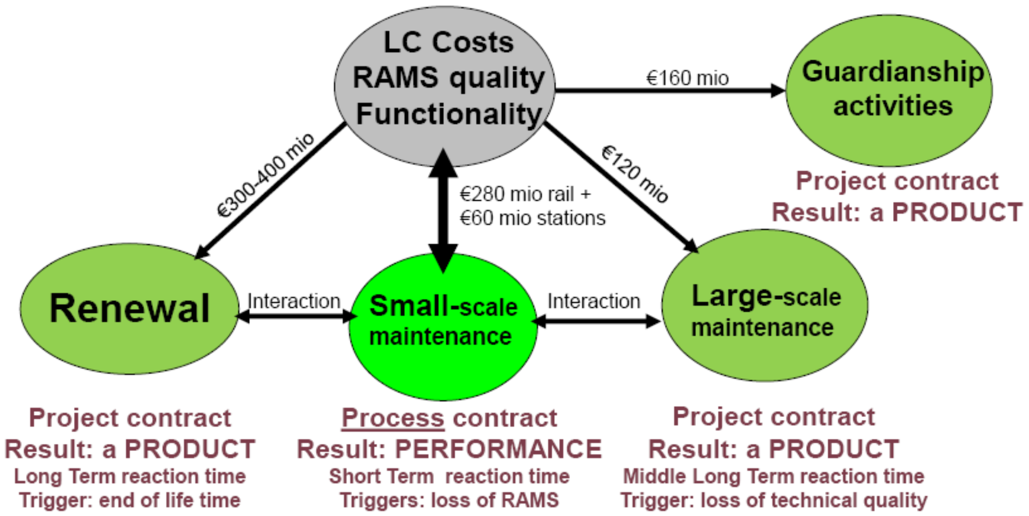


Figure 6-10 Distribution of funds within Pro-Rail, Swier (2005).

Life cycle costs and effects on RAMSHE (Reliability, Availability, Maintainability, Safety, Health and Environment) are the leading criteria for overall strategies and individual measures and projects at ProRail. High safety and reliability and low life cycle costs are sought, while meeting other business objectives as well.

From a strategic point of view, ProRail defined several principles to attain its overall objectives. The main ones are described below.

- Transparency in the relationship between activities, costs and performance. this relationship has to be well known and monitored, including operators performance.
- All decisions on new construction projects, maintenance or renewal must be taken on the basis of demonstrably lowest LCC.
- The data for asset management, financing systems and dashboards (KPI) must be available, reliable and managed at a sufficient level.
- Instruments (including procedures) and tools for supporting asset management, financing systems and dashboard must be developed.

A part from these general principles, a standard set of LCC based policy rules was defined for optimizing maintenance and renewal, and are described below.

- Standardisation and development of supply markets:

  Product specifications are reviewed and revised by ProRail in order to improve market entry for more suppliers. Nevertheless, standardisation remains a crucial need, not least for failure-critical components. It is advantageous for installation costs, spare parts management, training of personnel and quick repair and replacement. ProRail supports actively the development of European technical standards, in many working groups, as this serves the objectives of both standardisation and better functioning supplier market.
- Establishing high inherent quality:

  A basic rule is that money should be spent in robustness of assets, given that track deterioration depends strongly on initial quality. Heavy utilisation needs robust infrastructure. ProRail has had several examples on its network where projects delivered hard to maintain, failure-prone assets. The quality management systems have been enhanced in order to focus on certified, well-tested products in the infrastructure, without blocking good, innovative ideas.

- Removing unproductive assets:

  A basic starting point is that turnouts and track proposed for renewal should always be reviewed for potential rationalisation. This can result in quick wins for maintenance, but needs to be traded off in a total picture of costs and benefits from traffic control (routing possibilities) and infrastructure management.

- Preventing deterioration (causes) and removing damage at early stage: Pro-active maintenance is required in order to optimize LCC. Asset Management tools and degradation models are used by ProRail to achieve this goal.

According to Zoetman (2007), the track maintenance and renewal strategy adopted in 2000 and 2001 by ProRail will lead to a 10% reduction of the forecasted budget needs in the coming 25 years.

6.1.4 The Swedish Strategy

Trafikverket (former Banverket) is primarily funded by government grants and its activities are steered by the parliamentary transport policy goals, which is to provide a system of transport that is both economically effective and sustainable in the long term. To achieve this goal, Banverket developed a cost modelling that is depicted in Figure 6.11. This model based on LCC approach is only used for new investments, renewal or upgrading projects (not for maintenance), Prasad (2007)

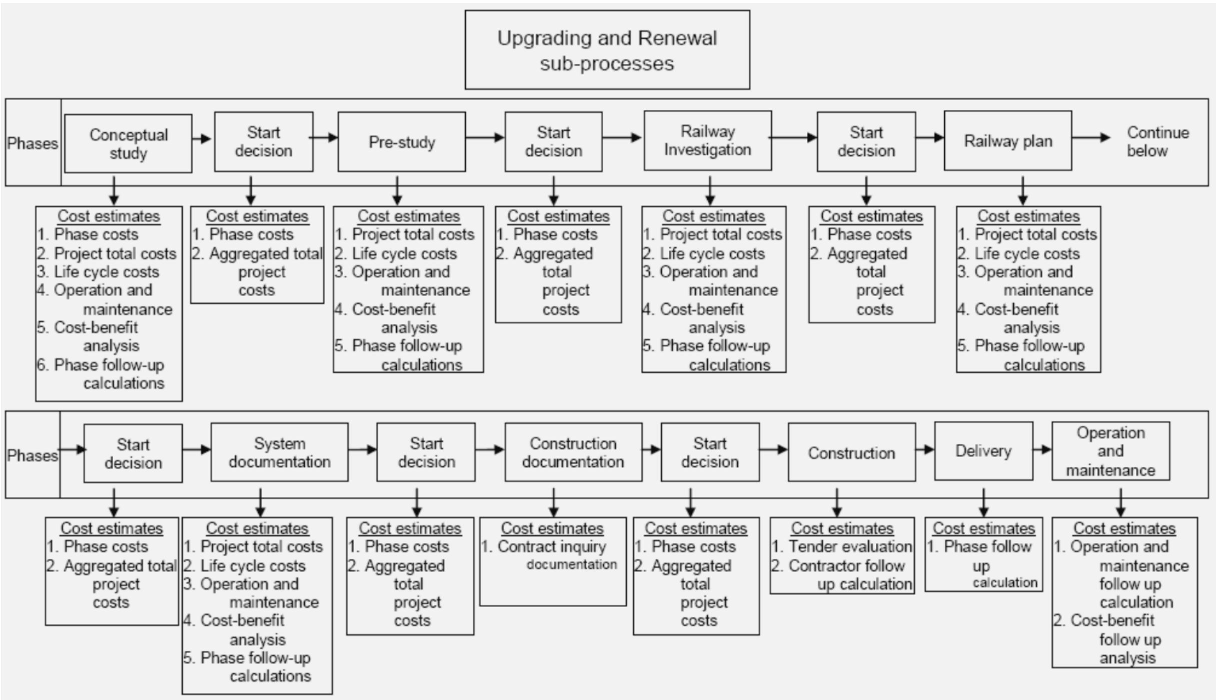


Figure 6-11 Cost model of Swedish Transport Authority. Prasad (2007).

The calculation in the pre-study is socio-economic and shows the gains for society. It is based on long lifespan of up to 60 years. Upgrading follows the same steps as new investments except the conceptual stage.

The decision for renewal is based on judgment of asset condition and analysis of the operation situation. The calculation of cost is based on historical data. If the renewal can be done within the annual budget, it is planned and done, but if more finance is needed, the process has to be reviewed in order to allocate funds for the forthcoming years, Orasad (2007).

LCC is considered in all decision-stages and for this reason, effective LCC procedures are required. The classification of the network according to track section characteristics contributes towards the objective of facilitating LCC calculations and analysis.

The Swedish IM also uses several databases and systems as tools to help the planning of maintenance and renewal works. Examples of this tools are BIS (track information system), BESSY (inspection system), 0FEIA (fault analysis system) and RFÖR (train delay system), Prasad (2007)

6.1.5 The Danish Strategy

With a total network of 3,240 km of track and 4.409 switches, the Danish railway network is operated by Banedanmark (BDK), which is a state owned enterprise under the Ministry of Transport.

An underinvestment on maintenance and renewal works caused problems in the reliability of the network, which became particularly evident in 2006. To overcome the maintenance backlog, state funding was increased by 33% with the aim of reducing the backlog to zero in 2014. With a total investment of 2bnDKK (around 260M€), the investment in track is 1:1 between maintenance and renewal. (Carter, 2007)

The strategy vision of BDK was defined in 2005 and it focused in three different areas of action: objective internal processes (prioritisation), asset management and performance.

The BDK system is a strong centralised prioritisation system, which results in standardised processes and decision criteria. The prioritisation is carried out with the help of an Excel based tool that provides structured answers to the consequences of not undertaking the work now on train performance, the cost of doing the work and the number of passengers affected (excluding delay). Also, a very clear hierarchy of routes has been agreed with stakeholders, to ensure consistent prioritisation of works.

Every month there is a priority meeting on proposed large scale maintenance and renewals with the asset owners of track, signalling, etc. (BDK outsources completely the maintenance of its network). As a result, a list of measures is produced with red, yellow and green prioritisation. The planning horizon for maintenance results from a prioritised list that is given to the contractors 15 months in advance. The next step of the prioritisation process is to incorporate objectives and a common set of criteria.

The asset management system works with a central database that provides static information to other applications and models. Examples of these models that are fed by the asset register are failure consequence model, which predicts direct and secondary delays, and track model, which predicts track condition from asset age and usage (line tonnage).

The information of the asset condition is updated after inspections. In this sense, track is manually inspected once a year, measurement trains runs four times a year and trolleys run every 8 weeks for visual inspection. Finally, BDK monitors usage and effectiveness of its asset management tools, in order to carry out open internal benchmarking.

6.2 Recommendations for optimising maintenance and renewal works of track and S&C

From the review of the M&R strategies developed by several European IMs, several recommendations can be drawn in order to increase the cost-efficiency and quality of both replacement and maintenance of railway assets. Moreover, further improvements derived from the work carried out in D3.3 are also included.

6.2.1 Integrated M&R strategy with systematic, transparent and objective decision-making processes

The planning of renewal and maintenance in a separate way has proven to lead to short payback and quick but not-lasting quality improvements. As a result, during the last decade there has been an ever-increasing awareness of the need of an integrated maintenance and renewal approach in order to minimize overall costs.

In addition, traditionally, decisions were made based on the historic knowledge of skilled workers. However, this approach is no longer accepted given that governments and public authorities providing funding, but also society and costumers (e.g. TOCs) demand transparent and objective decision-making processes. For this reason, it is important that the M&R strategy is provided with a well-defined criteria and a systematic workflow for the prioritisation of actions. One key element of this decision-making process is the life cycle costing, which is described next.

6.2.2 LCC: leading principle in M&R strategy

Life cycle analysis is widely accepted among IMs as the main principle leading the rationalisation of maintenance and renewal expenditures. As described in Chapter 6.1, the degree of implementation of the LCC approach varies significantly from one country to another (e.g. in some cases, LCC is only considered for investment projects with an associated budget over 3 M€, etc.).

LCC tools have been developed by several IMs and private companies to help the comparison and prioritisation of different alternatives which can be different maintenance regimes, different types of rail asset –sleepers provided or not with USP-, etc. Several IMs as ÖBB or ProRail have confirmed the advantages of using LCC approach – the later expects a 10% reduction of overall costs derived from the implementation of an LCC tool.

Moreover, the costs considered in the LCC can also vary between countries. The first LCC tools that appeared accounted for the costs of materials, maintenance activities and renewal works. However, recently the sophistication of LCC tools has increased and nowadays many IMs are able to consider not only direct costs but also indirect cost associated by operational hindrances caused by M&R interventions and speed restrictions. This operational indirect cost usually refers to the cost of train delays, rerouting, alternative bus services, etc.

However, the use of LCC tools has a clear drawback: in order to have reliable and accurate results, extensive information on track asset condition is required over many years in order to identify degradation profiles and other trends (e.g. mean time to failure). Notwithstanding, new automated and highly efficient inspection and monitoring equipment and vehicles have been developed in recently to facilitate the compilation of asset condition. The inspection and monitoring information is then organized in an asset management tool (AMT).

The complexity of the AMT depends on the amount and type of information stored. The more advanced AMT, such as that of DB Netz or ÖBB, record not only superstructure asset information but also geotechnical, signalling, OHLE, etc. information.

To facilitate the identification of degradation profiles it is recommended to classify the network according to its properties. The criteria for classification are specified by IMs, but the following factors have been identified as the most important ones:

- tonnage,
- speed,
- type of track (slab or ballasted track),
- radii and
- subsoil condition.

Track quality is often used as a key-figure to assess track condition. Furthermore, the grouping of line section in harmonised categories contributes towards the efficiency of LCC analysis –minimizes the number of prognosis to carry out- and enables the nation-wide comparison of degradation profiles for track sections with similar conditions.

6.2.3 Definition of strategic performance goals in M&R strategy and its monitoring

Achieving minimum cost of ownership has been traditionally the ultimate aim of IMs. However, the liberalisation of the Railway sector – which involved the entry of new TOCs to the network – together with the increasing demand from passengers of a better service have led to the introduction of new objectives more related to performance.

For this reason, the definition of strategic goals to attain performance-oriented prioritisation of actions is recommended. These strategic goals are commonly based on quality, reliability, availability and/or safety along with LCC.

The inclusion of key performance indicators in maintenance and construction contracts is already a common practice in many countries, and it is widely accepted by contractors. The price of the works is fixed based on the Service Level Agreement (SLA) signed between the IMs and contractor. The monitoring of the work executed is mandatory in order to assess the compliance with the SLA but is also crucial for determining the effectiveness of M&R

activities, which will be introduced in the AMT to increase the accuracy and reliability of degradation patterns.

Furthermore, by carrying out the monitoring of works quality, it is possible to assess the effectiveness of the policies and rules and the achievement of the M&R strategic goals. For this reason, these strategic targets must be designed so as to enable their monitoring, assessment and benchmarking.

6.2.4 Further prioritisation criteria: importance of the line

As mentioned previously, LCC represents a useful tool to compare several scenarios in terms of lowest cost of ownership, which is key for the prioritisation of actions. Nevertheless, there are other criteria that can determine the planning of M&R activities.

As explained before, a part from minimum LCC, availability, reliability, safety and other performance-oriented objectives are defined in the M&R strategy to meet end-users and state government demands. Because of this, improvements on the most densely traffic routes contributes the most to the achievement of overall performance targets, given that a higher number of passengers and TOCs benefit from them. Taking this into account, many IMs decided to incorporate an additional factor on the prioritisation process: the importance of the line route. The importance of the line is usually calculated according to the speed, number of train and tonnage.

6.2.5 Optimisation of work planning and scheduling

Planning time frames play a fundamental role in the M&R strategy. By planning M&R activities with sufficient anticipation, slots can be better negotiated with passenger and freight operators to increase track possession time. Furthermore, by planning interventions well in advance, alternative routes can be established if required and costumers can be better informed.

As an example, in Denmark, possession times are usually 3.5-4 hours for smaller activities. However, for longer activities, such as rail grinding, work is planned one year ahead, in consultation with the operators, to arrange up to 8 hours of track access.

M&R overall planning is usually carried out once a year. However, for the planning of important renewal or construction projects (i.e. investment usually over 2 or 3 M€), the planning can start between 3 to 5 years in advance.

Long-term planning was associated in the past with the uncertainty of budget provisions. Nonetheless, being aware of the importance of railway reliability, central governments have agreed to plan long-term funding to IMs, such as the Capacity and Funding Agreement (LuFV) in Germany, that guarantees the availability of funds for a sufficient time of period.

6.2.6 Bundling of construction and maintenance capacities

The cross-regional bundling of construction capacities offers benefits for IMs as well as for track contractors. By combining several renewal or maintenance works, the “time loss” due to the transport and set-up of the machinery is minimized, which results in an increase of work and cost-effectiveness and track availability (i.e. less operational hindrances). By increasing the “productive working time”, contractors are able to reduce the unit price (e.g. €/km) of the service, which benefits IMs, while their profit increases as a result of higher machine outputs.

To organize the bundling of M&R works, the “corridor concept” used by DB Netz can be used. The network is divided in several corridors, which enables a reliable site and train operation planning. In 2009, about 500 km of track renewal were combined to form machine lots in Germany. These lots have an average length of 50 to 70 km and are placed on the market as early as possible in order to achieve better prices, but also to achieve a reliable long-time planning.

There is a similar “corridor” concept in UK, called “Rules of the route”, under which it is agreed, usually for a period of several years, when a particular section of line can be made available for engineering work. Hence, for instance, the line between Newport and Swindon (roughly 100km in length for which a diversionary route via Gloucester is available) is closed for several successive weekends at roughly the same time of year and all major engineering work on the affected stretch of line is carried out then. There are also limits on the length and severity of speed restrictions that can be imposed which dictates how many work sites can be active at any one time.

6.2.7 Standardization of proven and robust assets and innovations

The standardisation of railway assets has several benefits. Firstly, the use of components with proven robustness guarantees a low failure risk, resulting in a high inherent quality of the infrastructure. Secondly, by employing standard assets, training of personnel is easier which results in higher outputs and hence, less costs of installation. Also, it facilitates spare parts management and repairing works. And finally, the standardisation of assets contributes towards the opening of the market (i.e. improving market entry for more suppliers). According to this, the development of European technical standards is then aligned with the interests of European IMs.

However, the employment of standard assets must not affect the development of innovative products and ideas. Notwithstanding, innovations must prove their robustness in extensive laboratory and experimental tests before being considered as an eligible product.

An example of an innovation that has been incorporated as a standard product (with its associated specifications) after the demonstration of its benefits, are the under sleeper pads (USP). Their main benefits are described in chapter 01.

6.2.8 The importance of track quality in M&R strategy

As said before, the use of standard and robust assets enables a high inherent quality, which not only prevents failures but also minimizes track degradation. Statistical analyses carried out in Sweden by Banverket showed that total maintenance costs are influenced by track quality and asset failure rates, as shown in Figure 6.12. As an example, considering that the average track quality of Network Rail is assumed to be moderate (Q-figure of 70) and that the average rate of infrastructure incidents per track and km and year is two (according to UK Infrastructure Condition Report), a reduction of 13% of maintenance costs results from an increase of track quality from Q-70 to Q-80. Moreover, if the robustness of infrastructure is increased (passing from two to one infrastructure incident per track and km and year), an additional 12% of savings could be achieved.

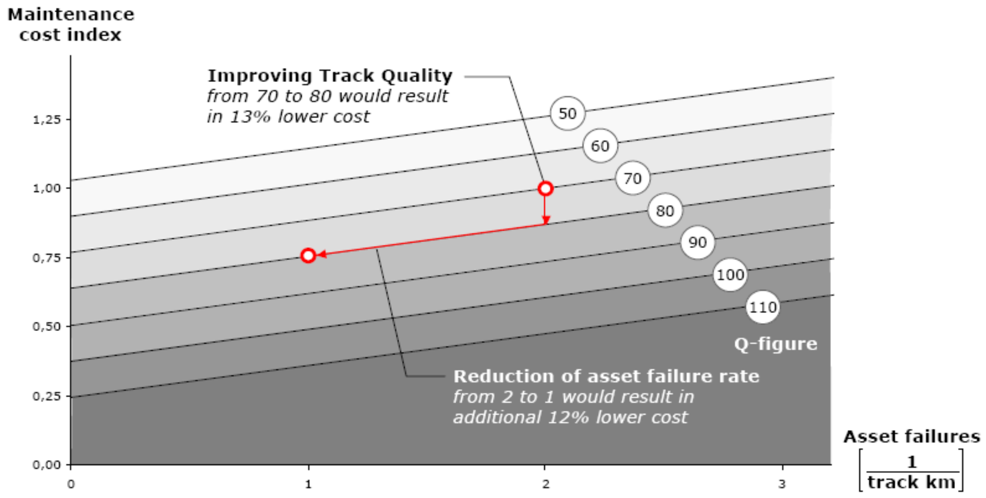


Figure 6-12 Effect of track quality on maintenance cost and asset failures, Network Rail (2008).

According to this, special attention must be paid to new materials and improved renewal methods that provide the highest possible quality of installation. Additional information can be found in ML-D3.3 (2014) regarding this issue.

6.2.9 Innovations to improve maintenance effectiveness and output of interventions

From a better planning and scheduling of works, as well as from a better prioritisation of actions based on LCC, overall costs can be reduced. Notwithstanding, further cost savings and improvements in availability can be derived from more effective and efficient maintenance and renewal activities.

Possible improvements are described below:

- High output machines: the use of high outputs machines (e.g. tamping machine with four units) or the combination of several machines (e.g. track renewal train with ballast cleaning machine or grinding and tamping machines) can help to improve the output of the intervention. This output can be further improved if the bundling of construction capacities explained before is applied.

- Effective maintenance for recurring failure spots: Innovations in track maintenance such as over-lift when tamping can be useful to fight against track memory, which implies very frequent maintenance actions.

- Mobile workshop: Depending on the distance between tracks, works can be carried out without blocking the traffic on the adjacent track. ProRail is using this development for line with a distance between track greater than 4 m. New and upgraded lines are design with a track distance of 4.5 m in the Netherlands.

- Modular switch. The modular switch concept has the potential to halve the total duration of works, compared to a conventional replacement. This saving of time comes from the fact that the (a) switch is assembled only once at the factory and it is transported, even with the driving devices, just in time to the installation time; (b) the transfer of the switch from the wagon to its final position is faster and (c) commissioning can be done also faster . This results not only in a significant reduction of track possession and labour costs, but also avoids the need of negotiations with landowners in case there is no l space available for switch assembly.

- Automated ballast collector: Used usually in combination with the modular switch method, the automated ballast collector can be used to increase the efficiency of the ballast layer removal and site preparation. However, it could offer the same reduction of time and labour needs when used with the pre-assembled method.

- Reduction of track stiffness variation.

Further information of these improvements can be found in ML-D3.3 (2014).

6.3 Methods for S&C replacement

Switches represent a key asset of the railway infrastructure, which must be replaced with higher frequency than plain track given that they have to bear higher stress. There is a wide range of methods being used to replace switches and crossings (S&C), which offer different outputs and installation qualities.

A brief review of the most common and best-practice renewal methods for turnouts are presented, as well as guidelines for helping engineers to identify the most suitable method(s) according to main decision-making parameters (cost, time, quality of installation, etc.).

6.3.1 Brief review of S&C renewal methods

6.3.1.1 Classification of S&C replacement methods

All methods for S&C renewal fall into one of these three categories:

- Assembled in situ
- Pre-assembled in the vicinity of the works
- Modular switch (just in time)

According to DB, the proportions of these three methods is 9% pre-assembled in situ, 90% pre-assembled at the lineside and less than 1% for modular switch. This proportion is very similar to the majority of the countries analysed in the report. Only in some Eastern

European countries the proportion of switches assembled in situ is higher. In contrast, Network Rail and SBB are the only Infrastructure Manager of the project that uses the modular switch concept with certain frequency.

6.3.1.2 Structure of S&C replacement methods

Beside the differences between methods, all follow a similar structure, which is described here-after:

Pre-renewal works

- Preparation of storage areas
- Transport of replacement components to site
- Pre-assembly of the new switch in the storage area (in case it is required)
- Topography works previous to installation

Removal of the old S&C and site preparation

- Dismantling and removal of the old S&C
- Removal of the upper part or the whole layer of ballast

Installation of new S&C

- Adding of new ballast (and optionally placing of geogrid)
- Laying and assembly of the new switch panels
- Welding or clamping
- Initial track geometry restoration
- Control system commissioning
- Final commissioning and testing
- Dynamic Track Stabiliser (optionally)

Post-renewal activities

- Welding and stress release (if it is not done during the installation phase)
- Final track geometry restoration
- Final inspection and acceptance

6.3.1.3 Pre-assembled S&C renewal method with excavators

The use of excavators is a common method in many countries (such in Spain, Eastern Europe, etc.), since it is usually the most economical. To remove the old switch and to install the new switch, two hi-rail excavators are used. When there is a parallel track, the hi-rail excavators run over it from the storage area till the location of the switch renewal. Given that their load capacity is between 5 and 8 tones, and also to minimize the deflection during transport, the switch is usually divided in three segments: switch, closing and crossing panels.

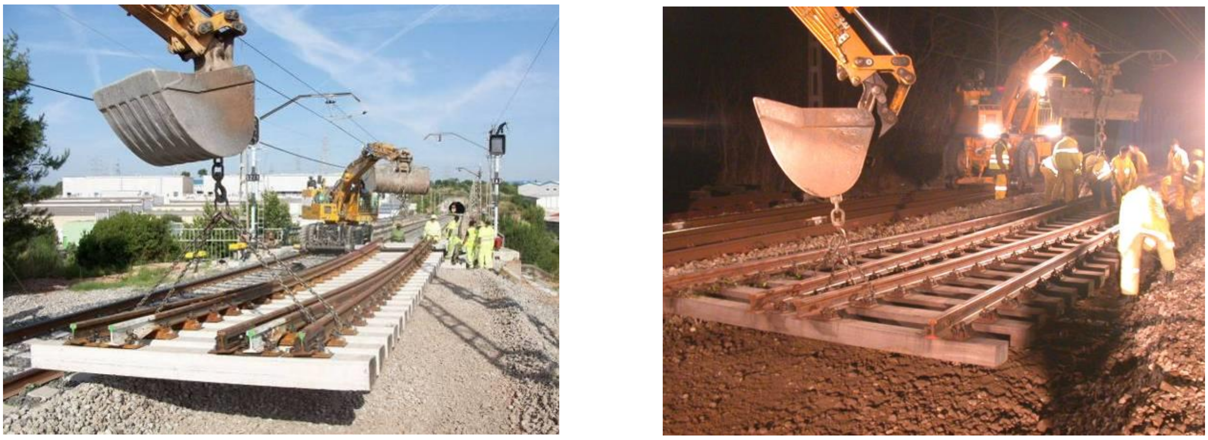


Figure 6-13 Installation of new switches in panels by rail-road excavators, COMSA.

Excavators have the advantage that they are low cost, widely available and very versatile. By changing the end of its arm, the excavator is able to carry out several tasks (from transporting the switch panel to removing the old ballast layer).

Nevertheless, the use of excavator for switch handling is not recommended since the switch panels can suffer excessive deformations. For this reason, other machinery more specialized to handle switches is advised. Moreover, the S&C renewal with excavators usually requires more labour, and for that reason is usually used in countries where wages are low.

6.3.1.4 Pre-assembled S&C renewal method with cranes

There can be found a wide variety of cranes that can be used during a switch renewal. Cranes can be classified by:

- **Lifting capacity**: is the main feature of the crane, given that it determines if the crane can handle the switch in one piece or if it has to be divided in several panels. The lifting capacity depends strongly on the extension of the boom of the crane. Lifting capacities from cranes commonly used for switch renewals may vary from 40 to 160 tones. On the other hand, the cranes are able to extend their arms so as to reach objects up to 20 m away from the crane.

- **Railway or road cranes**: railway cranes refer usually to cranes installed on bogies that are able to move along the track. These type of cranes offer much more flexibility than road cranes, which can only access the worksite if there is trackside road access.

- **Handling of the switch**: the switch has to be handled in a way that it does not suffer excessive deformations. Cranes can lift the switch panels by using a special beam that suspends the panel at several points or they just can lift the switch at only two points. The latter should be avoided if the panel has a considerable length, given that it will result in undue deflections during transport. In some cases, due to the high weight of some switches, two cranes have to be used simultaneously (as shown in Figure 6.14).

Figure 6-14 Different handling systems for switch renewals, Kranunion and TCDD.

A clear advantage of using crane for switch laying when compared to excavators is that, if provided with the longitudinal beam, the switch is lifted by multiple points, achieving a better quality of installation.

Another advantage of using cranes is that they can perform several tasks apart from switch laying; they are also used for track laying and for accident service (e.g. removal of carriages after a derailment). For this reason, IMs use to own several of these cranes, which makes them available for switch renewals.

6.3.1.5 Pre-assembled S&C renewal method using crane-beam systems

Crane-beam systems could be also include in the crane group described before, however, it presents some significant differences from railway cranes such as the Kirow Multitask cranes, and for that reason they are described separately.

Crane-beam systems are composed by two cranes supported by caterpillars that allows them to move on the ground, although some systems can be also be provided with special wheels to run over the track. The two cranes support a metallic beam that serves to give stability to the system and to lift and place the switch. Depending on the system, the caterpillars are able to rotate 90 degrees, which can be very convenient when the new switch has been pre-assembled at the side of the old switch.

Figure 6-15 Transportation of a switch with the DESEC system, DESEC.

The speed at which the crane-beam systems can move is very reduced, around 1 to 5 km/h. Hence, they are not recommended if there is a relevant distance between the pre-assembled new switch and the installation area. However, some systems allow to be pushed by a rail/road vehicle.

The lift capacity of crane-beam systems can vary significantly depending on the system. A typical range of admissible load is between 30 and 60 tones. On the other hand, the admissible length of the switch varies also from 35 to 50 m. In some cases, two crane-beams can work together to install a complete switch.

Crane-beams also offer the advantage of handling properly the switch, by supporting the switch at several points avoiding the bending or sag. They can be remotely controlled and thus, the labour can be reduced.

Some of the crane-beams, such as DESEC TL, can be transported by rail on flatbed wagons, as shown in the figure below.

Figure 6-16 DESEC TL being transported by platform wagons, DESEC.

As a disadvantage, this type of machines is very specific and usually expensive, so they are not as widely available as cranes or excavators.

6.3.1.6 Pre-assembled S&C renewal method using Geismar UWG laying system

The UWG system can be used for dismantling the old switch and for laying new pre-assembled S&C without the need of dividing the switch into several panels. The UWG laying system consists of:

- Self-propelled **hydraulic jacks PUM** or portal cranes, designed for lifting and lowering the assembled S&C. Each jack is controlled by one operator.
- **Trolley MWT** that is hydraulically controlled from PUM, which is designed to transport the assembled S&C.
- **Auxiliary track** and connecting ramps with the adjacent track.

Figure 6-17 PUM jacks and MTW trolleys during switch renewal, GEISMAR.

The PUM jacks lift the switches by means of clamps that grip the rail head on one side. These clamps can rotate for 180 degrees so that the rails can be held both ways - inside and outside. In addition to the clamps, two locking chains are placed on each side of the jack and therefore the lifted load cannot fall down.

The trolleys are equipped with stool, which can be shifted from the central axis. This enables to avoid obstacles during transport (signalling, platforms, etc.). During the installation it is possible to shift S&C by lifting jacks in the transverse direction. This ensures the accuracy of laying.

The main advantage of this system is that the switch can be removed or installed entirely, without the need of dividing it into panels. Thanks to its modular concept, it is able to handle switches from various lengths and weights, by adding or removing more jacks and trolleys. This implies that the pre-assembled switch can be welded before the installation, assuring that there will be no traffic over clamped rails.

Moreover, this system guarantees a correct handling of the switch given that it is supported by several points.

On the other hand, this system has two main disadvantages:
- It is a very specific machinery with higher investment costs.
- The UWG systems requires of one operator to control each PUM jack. This result in an increase of labour costs, but also the synchronisation of the jacks is human dependent.

6.3.1.7 Pre-assembled S&C renewal method using Geismar-Fasseta portal cranes

The Geismar-Fasseta system could be seen as an evolution of the UWG system. It is composed by several portal cranes (also called PEM jacks) that are able to move in a synchronised way (they are radio controlled). Each crane is provided by two wheels that allow them to circulate over the rails (of the track or of the switch to be transported) and by two lateral arms that can be deployed to support the crane onto the ballast. Each portal crane has a self-propelled trolley associated (LEM trolley), that can run over the track, and which transports the switch until its final location.

The number of portal cranes to be used depends on the length and the weight of the panel that is being transported, and the maximum allowed deflection. Each gantry/trolley combination is able to handle a 20 tonne load. In practice, the distance between independent cranes is usually between 10 and 15 m, which means that for the transport of one HS switch panel, from 3 to 7 of them are required.

The installation process of a switch panel using the Geismar-Fassetta system can be summarized in the following steps:

- Firstly, the portal cranes and the self-propelled trolleys are unloaded by an excavator from the train platforms, where they are transported, and distributed along the switch segment.
- The switch panel is lifted in a synchronized way by the portal cranes that are supported by their lateral arms onto the ballast.
- The self-propelled trolleys move by radio control until they are under the portal cranes, which retrieve their lateral arms. This way, both the portal cranes and the switch rest totally on the trolleys.
- The trolleys take the switch to the installation location, where the portal cranes extend again their lateral arms to support the switch and to release the trolleys, which move out under the switch.
- Next, the auxiliary rails placed in the installation area to allow the access of the trolleys are removed by excavators, and the switch is laid by the portal cranes.
- Once the switch is in its right position, the portal cranes are loaded again onto the train platforms by an excavator, which moves them back to the spot in the line where the remaining pre-assembled switch panels are placed.

Figure 6-18 Photos of the installation of a high-speed switch with Geismar-Fasseta system, COMSA.

For the installation of a complete high-speed switch it is required about 1 day (8 hours), and can involve up to 18 workers.

6.3.1.8 Modular switch method

Modular S&C or just-in-time method usually refers to the fact the S&C units are assembled at the factory as the whole unit, or in 2 or 3 large parts, and then transported to the renewal site using specialised wagons during the renewal works. The S&C units are then transferred directly from the tilting wagons to their final position as complete assemblies, thus maintaining the geometric quality of the S&C. Railway cranes, crane-beam systems or portal cranes can be used for the switch unloading from the tilting wagons and laying of the switch on its final position.

The implementation of the modular switch concept can result in significant savings of time and resources if compared with the pre-assembled systems. These savings are explained here below:

- Pre-renewal works: there is a significant time and cost savings incurred through the need to assemble the S&C unit once only at the factory. This avoids the time and labour required for the pre-assembly of the switch but also the need of negotiation with landowners if there is no lineside space available.
- Delivery and installation: delivery of the S&C panel can be made directly and just-in-time from the factory to the site in one train operation. The transfer of the panels from the wagons to its final position is made by railway cranes, and it is faster than for pre-assembled methods given that transport distance tends to be shorter.
- Commissioning and temporary speed restrictions: installation of the S&C panel in one piece ensures that the geometry and quality installed in the controlled environment of the factory are maintained as far as possible, resulting in time and cost savings from not having to fettle the S&C panel once installed. Moreover, there is also the belief that TSR could be avoided given that the quality of the installation is higher.
- Maintenance of post-installation quality: On the assumption again that the installation quality is improved in relation to pre-assembled methods, the subsequent rate of deterioration of the S&C panel in terms of track geometry and component condition is reduced.

Furthermore, along with the implementation of the modular switches, IMs tend to introduce other improvements to the switch renewal such as the use of the automated ballast collector or the use of an improved handling system of the switch to facilitate the lifting of the panel from the tilting wagon by the crane. These improvements result in further reductions of costs and labour.

In view of these advantages, many IMs have bought or constructed several tilting wagons in order to implement the modular concept in their switch renewals. However, except for SBB and NR, the employment of the modular switch method is very low in comparison with the pre-assembled method. This could be explained mainly because the number of tilting wagons owned by the IMs is limited, and hence, the number of switches replaced with this technique is very small compared to the total number of replacement. For instance, the number of tilting wagons owned by DB is about 6 or 8 wagons, while the total number of switch replaced per annum in Germany is around 2000.

The reasons why many IMs are not planning on buying new tilting wagons are:

- The investment cost of buying new tilting wagons is high.
- The pre-assembled method is a proven and straight-forward method that delivers a good quality of installation.
- Some of the time and resources benefits of the modular switch are based on a better quality of installation, while many IMs think that the quality is similar to that achieved with the pre-assembled method.
- The feasibility of delivering just-in-time the switch panels from the factory depends on the distance between the worksite and the S&C assembly factory. For that reason, in some cases, the modular switch is not an efficient method.

According to this, many IMs limit the use of their tilting wagons to those cases where trackside access road does not exist, there are lineside space constraints for the switch preassembly or have to meet a very short track possession time.

Tilting wagons are tailored to meet every network requirements. For example, in UK, tilting wagons had to adapt to narrow W6 gauges. The dimensions of the tilting wagons deck however are usually between 3.7 and 4.4m of width, allowing the transport of entire switches with up to 4.8 m-long sleepers and without dismantling the driving equipment. The deck length is usually between 22.5 and 28 m, while the maximum load of the panel is usually about 30 tonnes. Some tilting wagons also allow a lateral displacement of the loading platform from 0.5 m up to 1.2 m, to avoid any interface with adjacent track.

Conventional tilting wagons are able to transport EW 900 to EW 300 switches in three panels, while for smaller switches, such as the SBB type 185, two wagons are enough.

6.3.2 Comparison between S&C renewal methods

6.3.1.9 Parameters to be considered

The most important parameters to take into account when deciding which method to use for a switch replacement are the following:

- **Output** (track possession time): Track availability for engineering works is decisive when selecting a renewal method. Due to its complexity, the switch renewal cannot be completed during a single maintenance night shift, and longer closure times (e.g. weekend closures) are needed. The operational impact of the line closure depends on the availability of alternative routes, penalty fees, etc., but it is always a critical parameter in track renewal.
- **Need of lineside space**: Most common methods require lineside space for the pre-assembly of the switch, that if it is not available usually implies a costly and long negotiation process with landowners.
- **Cost of labour and machinery**: There is always a trade-off between the cost of labour and machinery. Whilst cost of machinery is more or less constant, labour costs vary considerably between countries. Hence, countries where wages are low tend to use methods involving higher work force instead of more automated and costly machinery.

- **Quality of installation** (line speed): The quality of the installation depends strongly on line speed because of the following reasons; (a) main lines usually are those offering higher speed, but also higher traffic/tonnage. The highest quality of installation is sought in those cases in order to minimize track degradation caused by traffic, but also to minimize the risk of a failure that would cause a high operational impact; (b) The size and weight of a switch depends strictly on the radii of the diverted track: low radii to allow higher speed on diverted track implies longer and heavier switch panels that require of a proper lifting to avoid undue deformations.
- **Availability of the system**: Due to the high amount of turnouts replaced annually, the availability of the system (i.e. machinery) represents also an important parameter. Due to the high cost of railway machinery, many contractors or IMs do not count with a larger number of very specialized machinery for S&C replacement (such as tilting wagons or Geismar-Fasseta portal cranes), but prefer more versatile machinery (such as rail-road excavators). This has to be considered when choosing the most suitable replacement method. For example, if the number of titling wagons available is reduced, the use of the modular switch should be only dedicated to those cases where it offers the highest benefit.

6.3.1.10 Recommendations for S&C replacement methods

The main advantages and disadvantages of each method are explained here-below:

- **S&C replacement using excavators**: the represent usually the cheapest and more flexible option, given that the machinery is widely available, low cost and very versatile (rail/road excavators can transport the switch and later remove the old ballast by just replacing the tool at the end of the arm). For this reason this method is commonly employed in many countries, such that of Eastern Europe, Spain, Turkey, etc. However, lifting and transport of switches by excavators can induce high stress and deformation of the switch that can affect their installation and future performance. This is why their use is not recommended for high-standard switches.
- **Road cranes**: the use of road cranes, presents very similar advantages and disadvantages to excavators. However, since they cannot circulate on the track, they can only be used when road access to the installation site is possible. Moreover, they need free space near the switch installation to place the road crane. Distance between the available space for crane positioning and worksite is critical to decide whether to use or not road crane system.
- **Railway cranes**: the most important benefit of the use of specialized railway cranes, such as Kirow crane, in comparison to excavators or road cranes is that the switch is more careful handled and exposed to lower stress and deformations. It is because of that, that many IMs use these systems as the preferred solution. They are more expensive than conventional cranes or excavators and they are able to run also on rails. Moreover, given that they are also used by IMs for other purposes (such as accidental service), IMs use to count with several of these cranes. Thus, they are usually more available for switch renewal than other specialized systems such as the tilting wagons or the crane-beam systems.
- **Crane-beam systems**: similar to railway cranes, they offer a good quality of installation due to a careful handling of the switch. The main benefit of this system is that it allows the switch to be transported entirely, without the need of dividing it into panels. This allows the welding to be done during the pre-assembling, avoiding the high stress on the rail due to the passage of trains when switch panels are provisionally clamped. On the other hand, the use of specialized cranes, such as

Desec TL 1200/TL 2000, is more expensive than conventional cranes or excavators and requires usually an additional train or special vehicle for their transportation.

- **Portal cranes**: similarly to Kirow or Desec TL cranes, UWG portal cranes are able to support the switch at several points and to transport and install the switch correctly without excessive deformations. As disadvantages, UWG system requires higher workforce than other systems, given that each portal crane is controlled by one person. In this sense, Fasseta system represents an evolution of UWG system, since one person can control remotely all portal cranes. Fasseta system is used for installing high speed switches given that it is able to transport longer switches than Kirow or Desec cranes.
- **Modular switch**: compared to pre-assembled S&C methods, the modular switch method is able to reduce significantly the total track possession, especially if combined with other innovative technologies such as the automated ballast collector (total time for the renewal can be reduced up to the half compared to conventional systems and labour can be reduced from 16 to 12 workers). It also has the benefit of avoiding conflicts with landowners given that this method does not require additional space for the pre-assembly of the switch. On the contrary, the modular switch requires the use of tilting wagons which are not always available due to its high costs. Moreover, the distance between the factory where the switch is assembled and the installation site plays a key role when deciding the suitability of this method. In what regards to quality, this methods offer similar quality than specialized cranes or portal cranes.

The advantages and benefits of these methods are summarized in the following table:

	Output (duration of track possession; total S&C duration)	**Need of lineside space** (for S&C pre-assembly)	**Availability of the system** (is the machinery required widely available? Is its use extended?)	**Labour** (number of workers required for installation)	**Machinery Cost** (cost related to the use of machinery)	**Quality of installation** (is the switch carefully handled during transport and installation?)
Excavators	++	+	+++	+	+++	+
Road Cranes	++	+	+++	+	+++	+
Railway cranes (Kirow,etc.)	++	+	++	++	++	+++
Crane-beam systems (Desec TL1200, VAIACAR, etc.)	++	+	+	++	++	+++
Portal Cranes (UWG, Fasseta, etc.)	++	+	+	+ (UWG) +++ (Fasseta)	++	+++
Modular switch	+++	+++	+	+++	+	+++

+++ Excellent performance
++ Average performance
\+ Poor performance

7. Conclusion

This Report helps to better plan the construction process, gives guidance on the choice of suitable replacement techniques and helps to include environmental issues in the planning process.

For IMs the operational availability of the network is very important as their revenue relies on this but is then reduced by the direct and indirect costs of maintenance or renewal works. Hence the cost for non-availability needs to be understood and should be minimised by precise and reliable planning of the intervention technique.

Here this report delivers guidance on:

- How to roughly estimate track possession costs.

These costs show many regional differences. Often the importance of the line and other special demands strongly influence this factor and the internal decision for the length of the track possession available. The report explains the most important parameters and the calculation of the general cost and shows how pre-planning well in advance influences the different factors.

- Best practice methods for the replacement of railway.

A significant risk minimization can be obtained by using best practice methods. While evaluating the different methods that are used across Europe it became very clear that IMs rely strongly on good and precise planning. This is one reason why many methods are being used for ages and are only improved to some extent. Planner and contractor are familiar with these techniques due to routine works that are easy to plan and conduct.

- The effect of national annexes to Eurocodes on bridge design

The comparison between Spanish and Swedish Eurocode calculations that was performed within the project offers an interesting perspective. It showed that the calculation with different factors from these two national annexes has practically no influence on the construction details. Of course “boxed values” represent different maintenance strategies and stand for a variety of financial policies of the member states. When it comes to constructional design and construction itself there is hardly a difference.

- Strategies for maintenance and renewal of track and switches and crossings.

A review of the common principles and best practices of several European IMs in maintenance and renewal –M&R– strategy has been carried out, such as the bundling of construction works in “site corridors” to maximize track possession times.

- Standard bridges

The development of European standard bridges for small spans seems to be promising. Earlier standard bridges were available in many European railway organizations. They were abandoned when railway organizations were split into IM and rail providers and, at the same time, new Eurocodes for design were developed. A standard bridge design that meets all various National Annexes (NA) to the Eurocodes would enable competition and reduction of costs for replacement of rail infrastructure.

Appendix A. Management of Bridge Replacements

The guidance below can be used as a tool for the infrastructure manager to handle a project from beginning to the end. The example below is based on a procedure used by Rail Net Denmark (Banedanmark).

Five phases are foreseen:

1. Conceptual design
2. Basic design
3. Detailed design
4. Execution
5. Hand over procedure

These five phases are illustrated in Figure A.0-1**Error! Reference source not found.**.

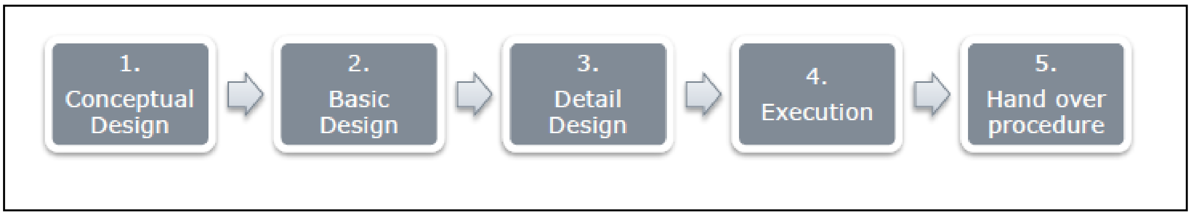


Figure A.0-1 Management phases for Bridge Replacement projects

Between each phase there is a milestone of deliverables and a number of choices to make before the next phase is started.

In the following sections each phase is described. Each horizontal rectangle – or lanes - represents the tasks of the three active participants: the IM, the consulting engineer and the contractor. Arrows between task boxes indicate the typical workflow. When task boxes overlap between lanes, the work is typically shared between the two parts. Dashed arrows or task boxes indicate workflow to be considered, but not necessarily to be followed. The arrows do not necessarily represent the contractual relationships between parts.

Duration of each phase varies from project to project. Complex projects might take years and easy projects perhaps only take a few months. Often time is the determining factor together with when and how line closure can be scheduled.

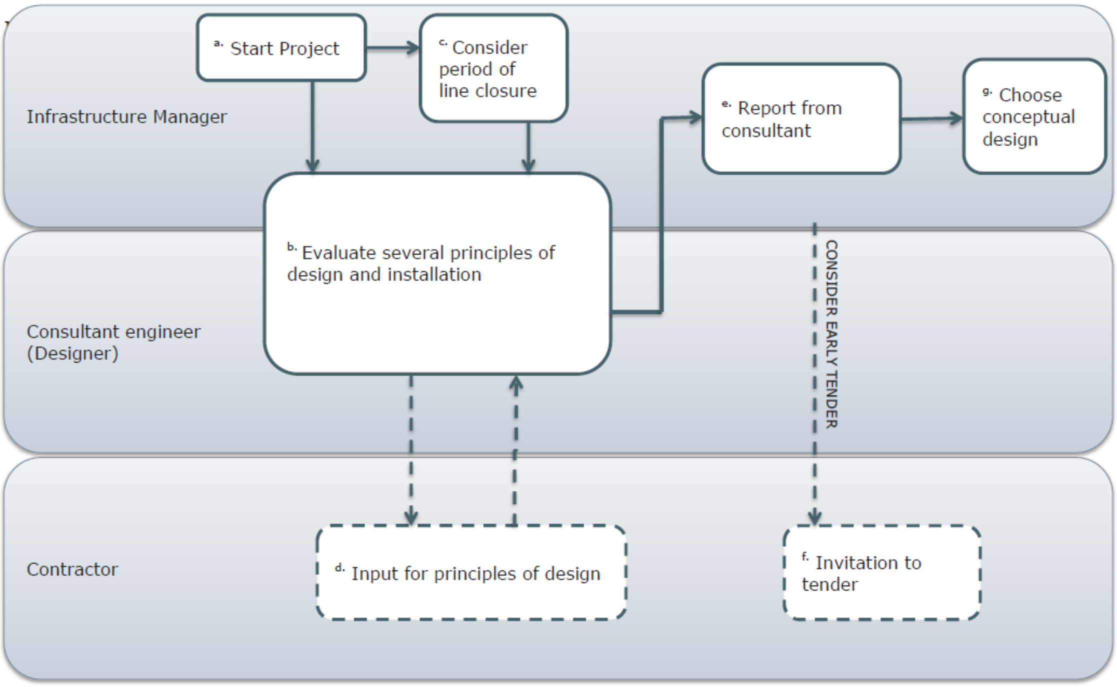
The model can be changed into other configurations, if another workflow is more favourable in a given situation or country. One thing that often varies is who the designer is. In general, it is often the consulting engineer or the contractor, but in some cases it might be the IM.

If Bridge Information Modelling (BrIM) systems are available, they may be used (refer e.g. to Section 4.2 in ML-D3.2 (2014)).

A.1 Conceptual design – Phase 1

When choosing the right concept for a project regarding bridge replacement, it might be necessary to evaluate several principles of design before choosing the conceptual design.

In deliverable ML-D3.2 (2014) “Methods for bridge replacement”, several suggestions of conceptual designs are described.



a) Initiation of bridge replacement.
b) Before considering various concepts, it is important to evaluate the given project. Parameters such as span and general size of structure, soil conditions, possible size of construction site, construction costs and of course the possible period of line closure need to be analysed. The tables in section 5.3.2 can be used to consider some of the principles of standard bridges described in ML-D3.2 Methods for bridge replacement (2014).
c) The possible window of line closure can often be the most important parameter in choosing the best concept. Therefore, it is important to investigate all possible alternatives as early as possible in this phase.
d) A contractor might bring up favourable principles to evaluate
e) The designer delivers all evaluated principles to a level that makes it possible for the IM to choose a conceptual design.
f) Choosing an early tender may be favourable for the infrastructure manager.
g) Phase 1 ends by choosing the conceptual design.

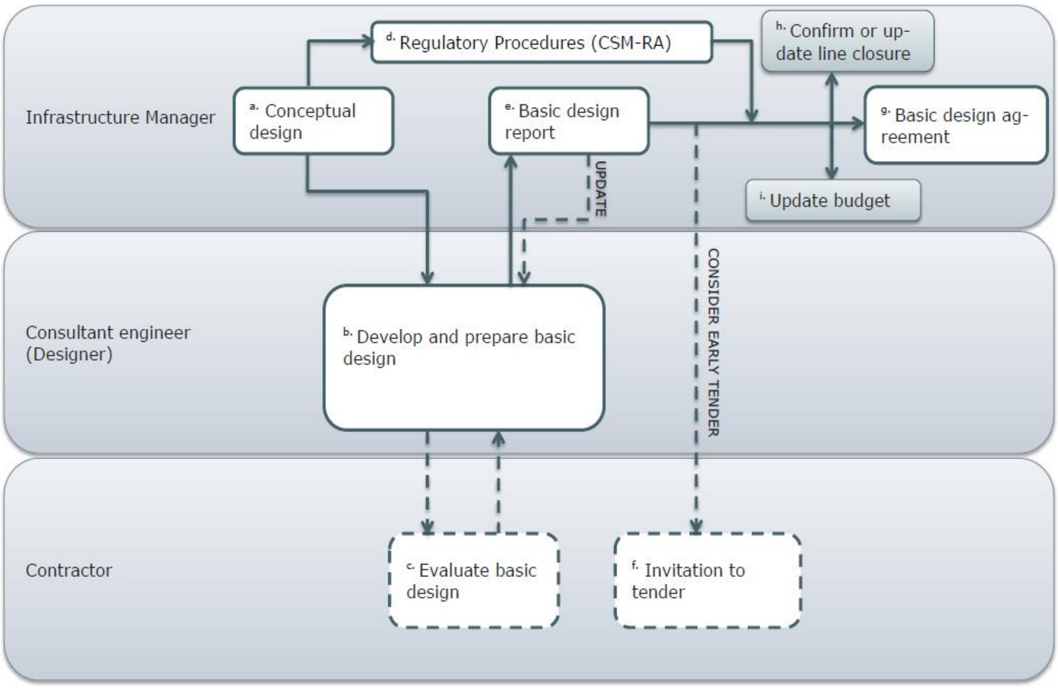
Figure A.0-2 Conceptual phase

A.2 Basic design – Phase 2

When the conceptual design is found, it is necessary to develop the project to a basic design. All necessary conditions are evaluated through this phase, and all effects on the estimated costs and period of line track closure are updated.

In this phase the regulatory procedures regarding Common Safety Methods on infrastructure projects (CSM-RA) should be considered, see e.g. EC 352 (2009) and ORR (2012a).

When the basic design is agreed upon the basic design phase is finished.



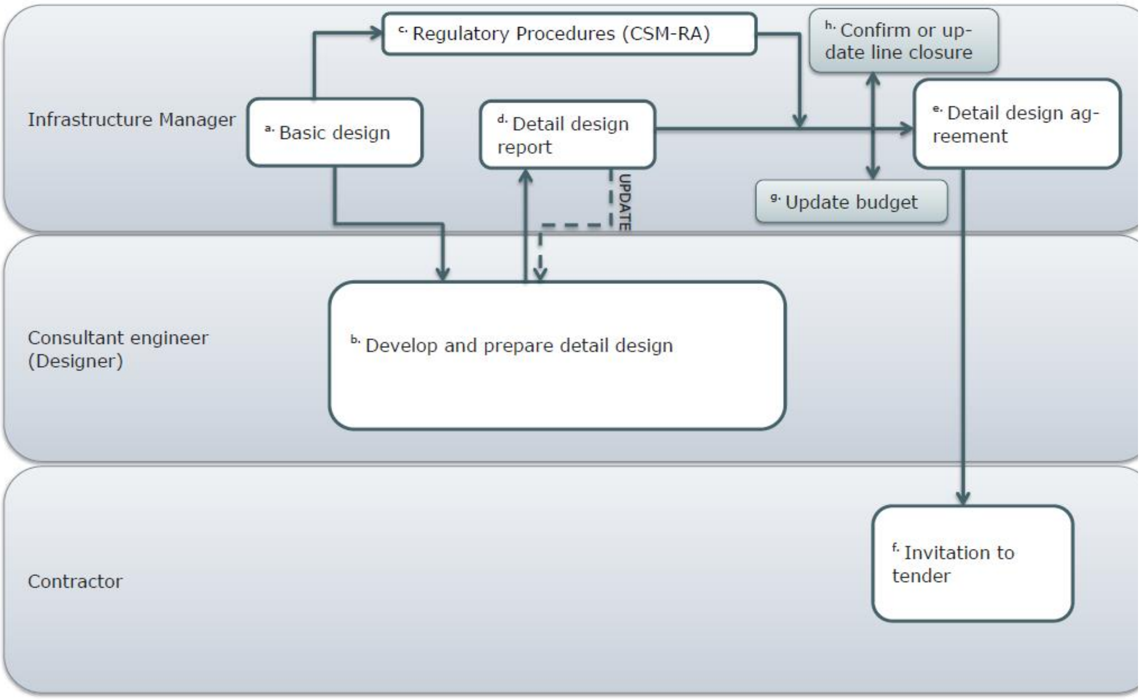
a) The conceptual design from phase 1 needs to be developed in this phase.
b) The designer develops the basic design.
c) A contractor might be included in this phase to help with the development of the basic design
d) Regulatory procedures can have an impact on the design or give limitations in the execution phase. Safety procedures necessary to follow on rail infrastructure projects need to be handled.
e) The basic design provided by the designer is evaluated. If the IM has other requests to the project, the basic design is updated.
f) As in phase 1, the IM can consider early tender.
g) Phase 2 ends by agreement of the basic design.
h) Period of line closure is confirmed or updated.
i) Budgets are updated

Figure A.0-3 Basic Design Phase

A.3 Detailed design – Phase 3

In phase 3 the designer develops the basic design to a detailed design suitable for tendering.

When the design is finished and the line closure is scheduled, the detailed design phase ends by invitation to tender.



a) The basic design is developed to the detailed design in this phase.
b) The main work of this phase is often the development of the detailed design.
c) The regulatory procedures are continued in this phase as the detailed project evolves and might cause the need for updated procedures.
d) As in the others phases, the detailed design is reviewed by the IM and any changes or updates are made.
e) When the detailed design is finished, the phase ends by agreeing on the design.
f) The detailed design is sent to tender
g) Budgets are updated
h) Periods of line closure are confirmed or updated and scheduled

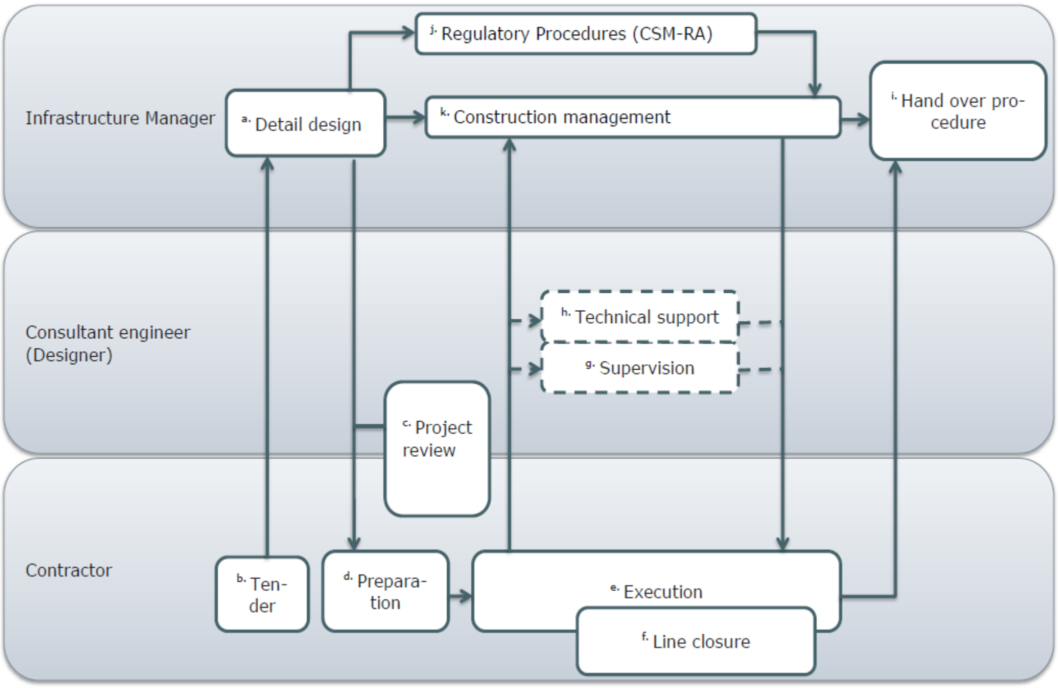
Figure A.0-4 Detailed Design Phase

A.4 Execution– Phase 4

In phase 4 the actual construction work and the line closure is executed. The line track closure is often only a minor period of the total phase.

The IM and the designer follow this phase by supervision and technical support and of course general management.

Phase 4 ends by the handover procedure.



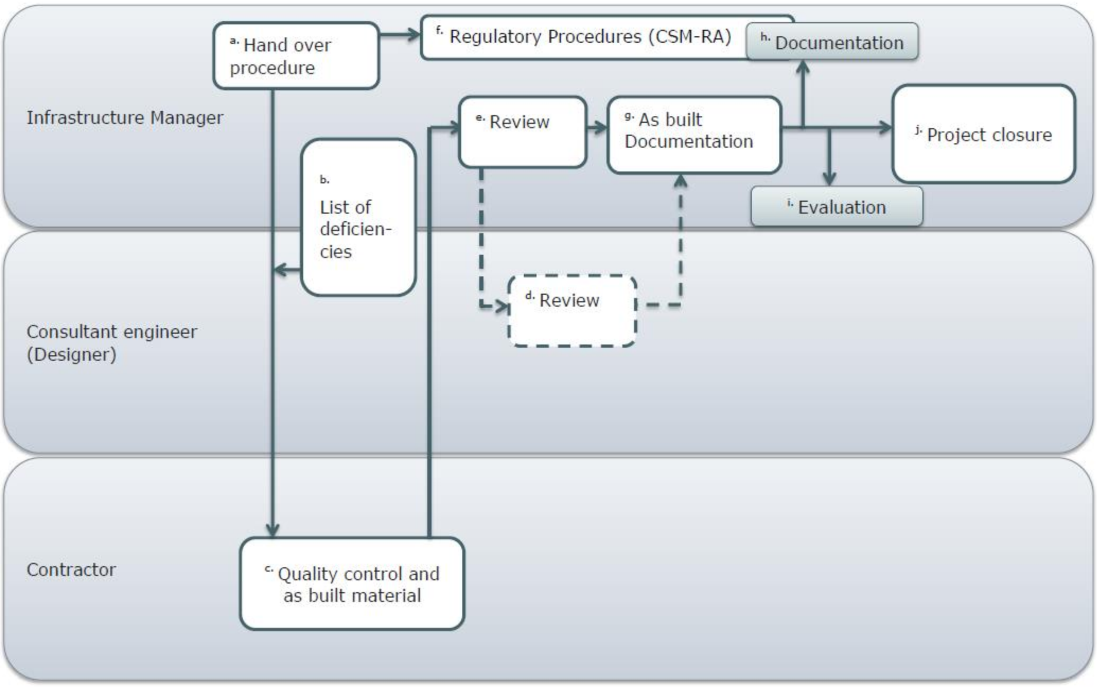
a) The detailed design is executed in this phase
b) When the tender is accepted, a contract can be signed
c) The designer reviews the project together with the contractor so that as much knowledge as possible is handed over.
d) A period of time is devoted to preparation for the contractor
e) Execution
f) The period of line closure is usually only a shorter period of the total execution phase.
g) Supervision must be executed and planned to ensure proper execution according to the tender documents and procedures in CSM-RA
h) Technical support might be necessary
i) When all civil works are done, the phase ends with the handover procedure
j) Necessary regulatory procedures must be continued and any regulatory demands must be followed
k) The IM follows the execution phase by general management

Figure A.0-5 Execution Phase

A.5 Handover procedure – Phase 5

Phase 5 involves getting all necessary information to the archive of the IM and documentation demanded as a part of the common safety management.

It also involves, of course, evaluating the progress of the total project for future similar tasks.



a) As the contractor has finished the civil works in phase 4, the handover procedure is arranged.
b) Any unfinished works are noted on the list of deficiencies
c) Quality control and documentation of all work is delivered together with as-built documentation. Any changes of the design are noted as a part of the documentation.
d) The IM reviews the documentation
e) The designer reviews the documentation
f) Regulatory procedures often require some kind of work that is only possible to deliver, when civil works are finished.
g) As-built documentation is updated after review.
h) Any kind of required documentation demanded by the regulatory procedures is delivered
i) An important session for future projects is to evaluate the finished project and determine, whether any choices could have been different.
j) Project closes

Figure A.0-6 Handover procedure

A.6 Example

As the presented managing tool is based on the procedures of Rail Net Denmark, several bridge projects have already been executed according to the model described above. One example is the Replacement of the Bridge over Ålekistevej in 2013 in Copenhagen, Denmark. It is described below.

Figure A.0-7 Picture of the bridge over Ålekistevej

In phase 1 several principles were evaluated (Renewal off the existing bridge; replacement of the superstructure with a new slim concrete bridge, a new steel bridge, or a new concrete bridge and heightening of the embankment and track). In the end it was chosen to exchange the bridge to a new slim concrete bridge with solid edge beams. The new superstructure was to be precast on scaffolding next to the rail line and afterwards moved into permanent position. Many conditions were evaluated, and the period of line closure had high influence on the selected conceptual design. If the existing bridge had been renewed, the total cost might have been less, but the impact on rail line traffic and total amount of line closures was much higher. Another important factor was which method suited the actual space condition, because all works had to be made on site in a densely populated area.

Once the conceptual design was chosen, phase 2 began. Regulatory procedures according to CSM (Common Safety Method) began. Contact to neighbours was established as adjacent gardens were temporarily expropriated to establish sufficient construction site. Overview of underground cables was established in this phase as well, and conflicting cables to new foundation was clarified. The conceptual design was developed to the basic design, and a contractor was contacted to evaluate the method of launching. Because the undergoing road had a lot of underground cables, the foundation of the launching system was challenging. When the basic design was finished, several unexpected costs were discovered, so budgets were updated. The period of line closure was confirmed to be 5 days or more precisely 128 hours.

Figure A.0-8 New concrete bearing shelf is casted during line closure.

In phase 3 the initial design was developed to detailed design. In this phase the consulting engineer was the busiest part. As a part of the regulatory procedures, the design was validated by an external consulting engineer. This led to a process of optimising the design and calculations between the 2 consultants together with the IM. When this process ended, the design was finished. The consulting engineer delivered an estimate of costs for all civil works enabling the IM to update budgets before tender. In phase 3 some works close to tracks were admitted, but these works were preparatory minor works and could thereby be executed in normal track closure during night-time.

Figure 0-9 Launching of the new superstructure.

In phase 4 the project was executed. To help the contractor, the project is reviewed together with the IM and the designer passing on all knowledge from the three earlier phases. A short period of preparation was given to the contractor, before the new concrete superstructure was casted during a period of 6 months, and the existing substructure was enhanced. In this period, all work was regularly supervised by the consulting engineer, who also helped with technical support through this phase together with Rail Net Denmark's construction manager. At the completion of all civil works, the construction manager arranged the Handover Procedure.

In the last phase the consulting engineer prepared the list of deficiencies as a part of the handover procedure. Some finishing works were still to be completed by the contractor. Furthermore, all as-built documentation was delivered by the contractor to the IM. The IM had his consulting engineer review the documentation and requested any missing documentation delivered. Afterwards the digital drawings were updated by the designer and delivered to Rail Net Denmark's archive. The new bridge over Ålekistevej was thereby in the hands of the general maintenance programme together with all other bridges of Rail Net Denmark.

Appendix B. Short standard bridges

In this Appendix some examples will be given of short standard bridges designed using the new Eurocode for concrete, EC2 (2004-2006). Trough bridges are a common bridge type used across Europe and such sections will primarily be studied, see Figure B.1.

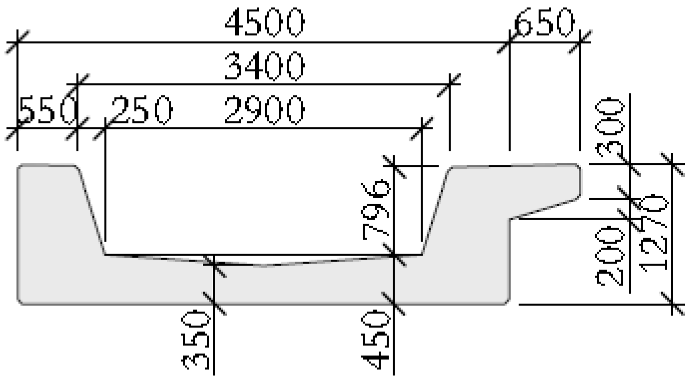


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Figure B.0-1 Typical section of a reinforced concrete trough bridge, Enochsson et al (2002)

B.1 Studies on trough bridges

For many small bridges over streams a trough bridge is a good choice.

Design examples using the new Eurocode for concrete, EC2 (2004-2006), have been developed in two MSc theses at Luleå university of Technology by Rodriguez (2014) and Diaz (2014). A summary of some of their results is presented below.

The aim of the work was to provide useful standard designs for short railway bridges with span lenghts of 3 – 9 m. The new Eurocodes were applied with National Annexes from northern and southern Europe (Sweden and Spain).

The following subjects were treated:

- Bridge geometry and materials used
- Durability requirements and concrete cover
- Permanent loads
- Variable loads – LM1
- Ultimate Limit State (ULS)
- Serviceability Limit State (SLS)
- Fatigue Limit state (FLS)
- Accident Limit state (ALS)
- Reinforcement design.

Some examples from the calculations for a 6 m bridge are given below. For non-standard notation and background to equations, see Garcia Rodriguez (2014) and Martinez Diaz (2014).

Bridge geometry and materials used

A typical drawing for a bridge with a span of 6 m is shown in Figures B.2.

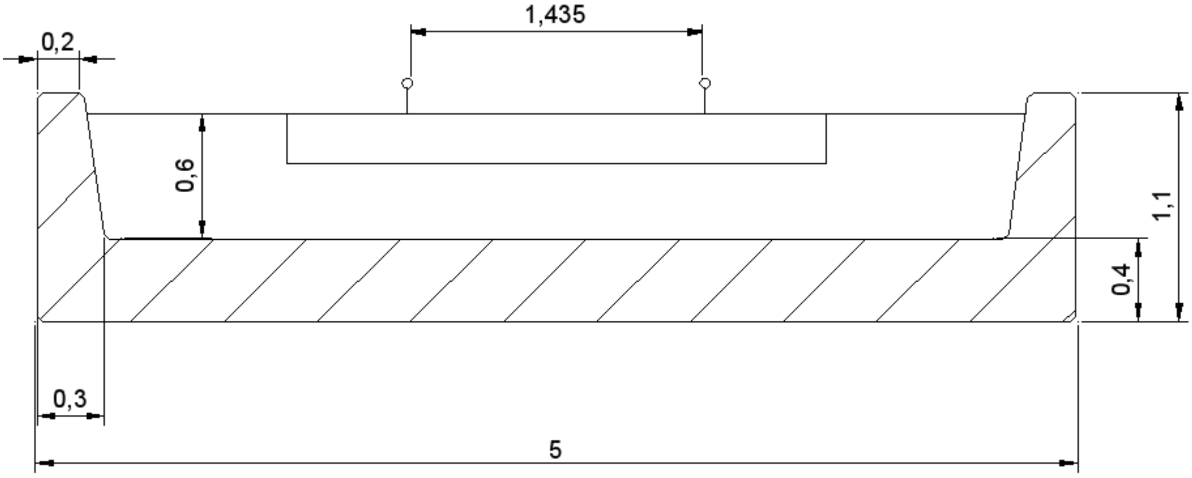


Figure B.0-2 Bridge Geometry, Garcia Rodriguez (2014), Martinez Diaz (2014)

The following materials were used:

Concrete C40/50 with density 25 kN/m^3

$$f_{cd} = \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_c} = 1{,}00 \cdot \frac{40}{1{,}5} = 26{,}67\ \mathrm{MPa}$$

$$f_{ctd} = \alpha_{ct} \cdot \frac{f_{ctk,0,05}}{\gamma_c} = 1{,}00 \cdot \frac{2{,}5}{1{,}5} = 1{,}67\ \mathrm{MPa}$$

Steel B500B with density 77 kN/m^3

$$f_{std} = f_{yd} = \frac{f_{yk}}{\gamma_s} = 435\,[MPa]$$

Ballast with density 20 kN/m^3

Sleepers UIC (AI 40) and rail of type UIC 60 are used.

Durability and cover to reinforcement

The safety class is Class 3.

It is assumed that the concrete surface is subjected to long term water contact and that corrosion of the reinforcement can be induced by carbonation. According to the EN1992-1-1 §4.1 Table 4.1, the exposure class to use in this case is XC2. The concrete cover c will be:

Longitudinal reinforcement: $\phi_{\mathrm{long}} = 20mm$

$$C_{nom} = 25mm + 10mm = 30mm$$

Transversal reinforcement: $\phi_{\text{trans}} = 16mm$

$C_{nom} = 20mm + 10mm = 30mm$

Permanent Loads

The dead load gives a maximum shear force of 72,3 kN/m and a maximum moment of 109,2 kNm/m in the longitudinal direction and 37,6 kN/m and 44,9 kNm/m in the transversal direction.

Variable Loads

The variable traffic loads give a maximum shear force of 36,8kN/m and a maximum moment of 298,4 kNm/m in the longitudinal direction and 117,9 kN/m and 166,7 kNm/m in the transversal direction.

Wind loads on the supports are 9,3 kN/m with a maximum moment of 22,8 kN/m

The braking force is 159,6 kN and the traction force 263,3 kN

The Ultimate Limit State (ULS) and Serviceability Limit State (SLS) loads are summarized in Table B.1.

		LONGITUDINAL		TRANSVERSAL	
		V (kN/m)	M (kNm/m)	V (kN/m)	M (kNm/m)
ULS	Eq. 6.10	161,05	659,26	256,75	359,84
	Eq. 6.10a	144,52	508,02	196,48	270,88
	Eq. 6.10b	144,63	581,32	226,30	314,20
SLS		111,08	409,28	158,34	218,41
MAX		**161,05**	**659,26**	**256,75**	**359,84**

Table B.0-1 Summarized Loads

The deflection in the SLS is 2,56 mm.

Reinforcement

Drawings of the reinforcement are given in Figures B.3 + B.4 and B.6 + B.7.

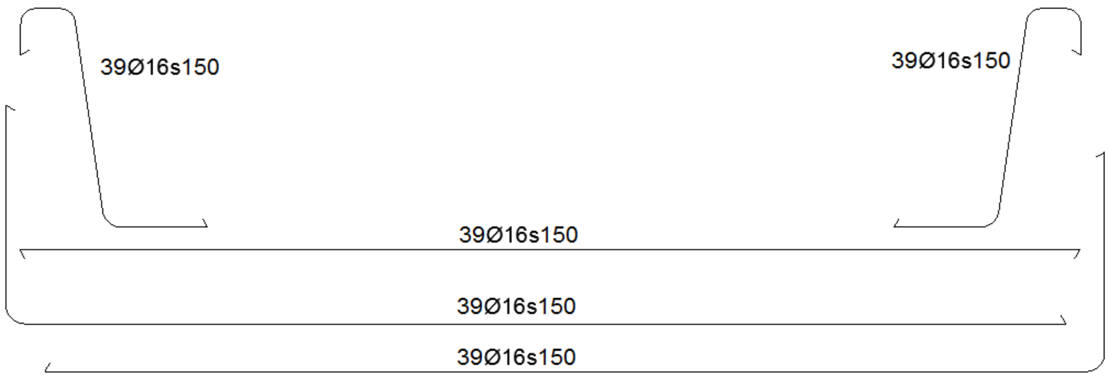


Figure B.0-3 Transverse reinforcement bars

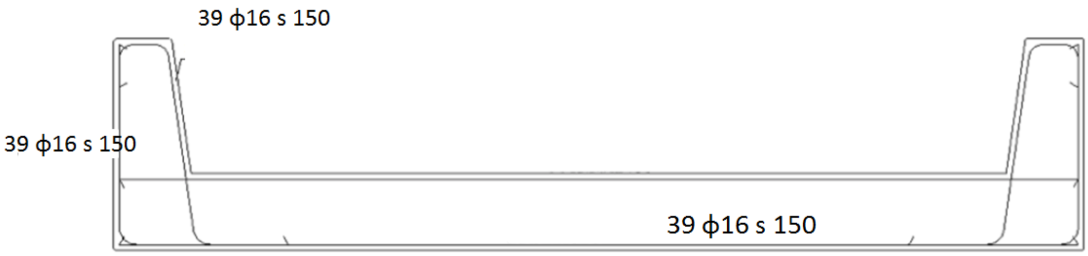


Figure B.0-4 Transverse reinforcement distribution

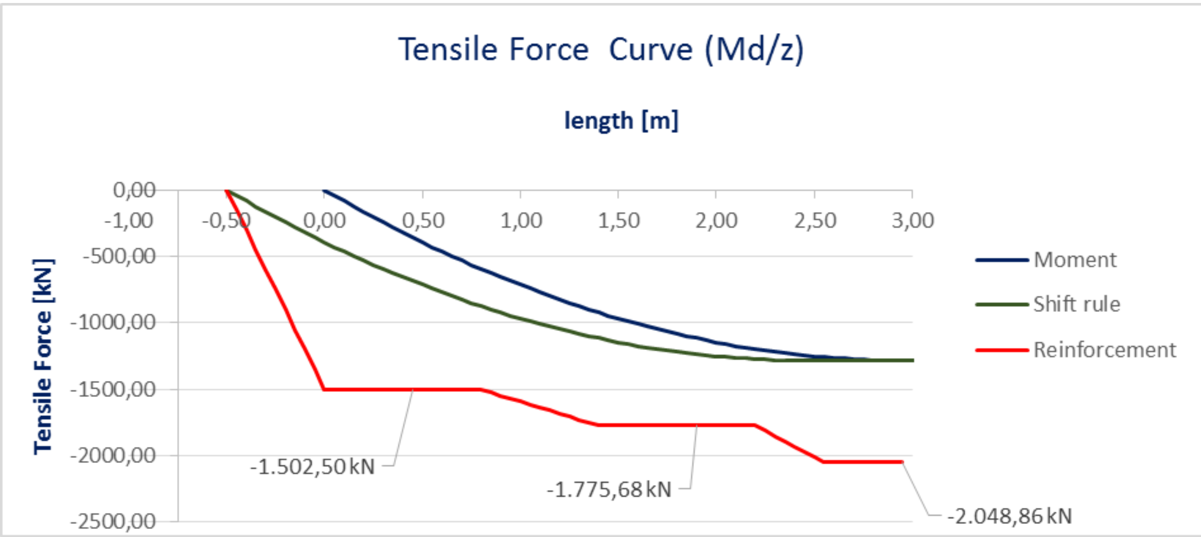


Figure B.0-5 Tensile force curve

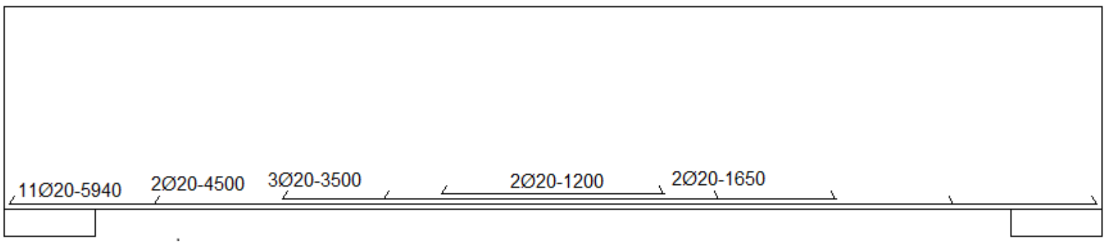


Figure B.0-6 Longitudinal reinforcement distribution

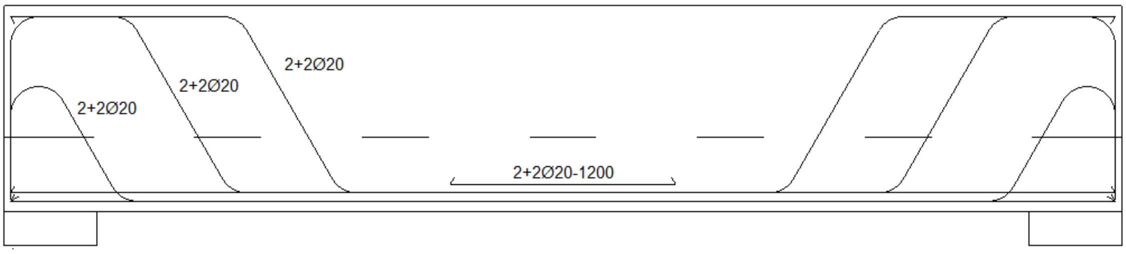


Figure B.0-7 Shear reinforcement distribution

Fatigue

For concrete

$$D = \sum_{i=1}^{8} \frac{n_i}{N_i} = 0{,}01 < 1$$

For 9 reinforcement bars in each beam, the condition of D<1 is not satisfied for 120 years of life that the bridge is designed for, so the number of reinforcement bars is increased to 10, obtaining the following results:

$$D_{Ed} = \sum_{i=1}^{m} \frac{n(\Delta\sigma_i)}{N(\Delta\sigma_i)} = 0{,}77 < 1$$

Final Design

In Figure B.8. a final design is shown. The amount of reinforcement for different span lengths is given in Table B.2 for a design according to the Spanish National Annex, Garcia Rodriguez (2014).

A comparison between designs according to the Swedish and Spanish designs is given in in Table B.3.

The main differences in the annexes are given in Table B.4.

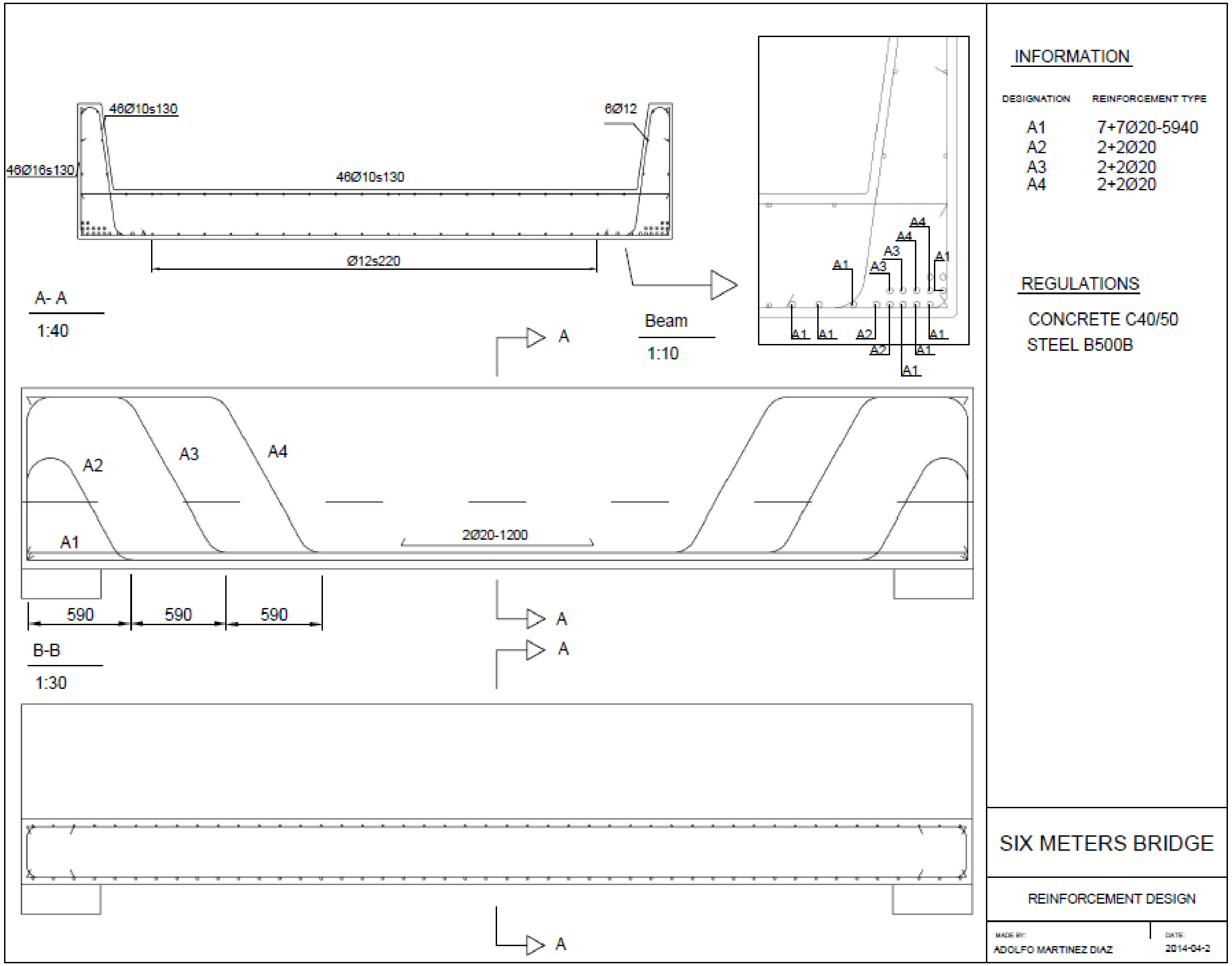


Figure 0-8 Design for a standard bridge with a span of 6m, Garcia (2014), Martinez (2014)

L [m]	WALLS	TRANSVERSE	LONGITUDINAL	MINIMUM REINF.	SHEAR	CRACK WIDTH [m]	FATIGUE
3	T: 0,20 B: 0,25	71Ø16s71	18Ø10	Slab: 27Ø10 Beam: 8Ø10	6 stirrups 310 mm	0,20 (long) 0,37 (transv)	Dc=1,1E-6 Ds=0,0326
4	T: 0,20 B: 0,25	52Ø16s75 58Ø16s68 (c)	10Ø16	Slab: 27Ø10 Beam: 6Ø12	3 st. 615mm	0,32 (long) 0,40 (transv)	Dc=1,2E-5 Ds=0,4217
5	T: 0,20 B: 0,30	65Ø16s75 74Ø16s67 (c)	16Ø16 17Ø16 (f)	Slab: 27Ø10 Beam: 8Ø10	4 stirrups 420 mm	0,27 (long) 0,40 (transv)	Dc=3,0E-4 Ds=0,5297
6	T: 0,20 B: 0,30	78Ø16s75 92Ø16s65 (c)	14Ø20 15Ø20 (f)	Slab: 19Ø12 Beam: 6Ø12	3 stirrups 590 mm	0,31 (long) 0,40 (transv)	Dc=0,0095 Ds=0,7732
7	T: 0,25 B: 0,35	84Ø16s83 110Ø16s63 (c)	18Ø20 20Ø20 (f)	Slab: 18Ø12 Beam: 8Ø12	4 stirrups 515 mm	0,28 (long) 0,40 (transv)	Dc=0,0135 Ds=0,9486
8	T: 0,25 B: 0,35	96Ø16s83 126Ø16s63 (c)	15Ø25 17Ø25 (f)	Slab: 18Ø12 Beam: 8Ø12	3 stirrups 740 mm	0,32 (long) 0,40 (transv)	Dc=0,4232 Ds=0,7368
9	T: 0,30 B: 0,40	108Ø16s83 144Ø16s62 (c)	18Ø25 21Ø25 (f)	Slab: 18Ø12 Beam: 8Ø12	3 stirrups 690 mm	0,31 (long) 0,40 (transv)	Dc=0,4868 Ds=0,7418

Table 0-2 Summary of Results for Spanish National Annex, Martinez Diaz (2014)

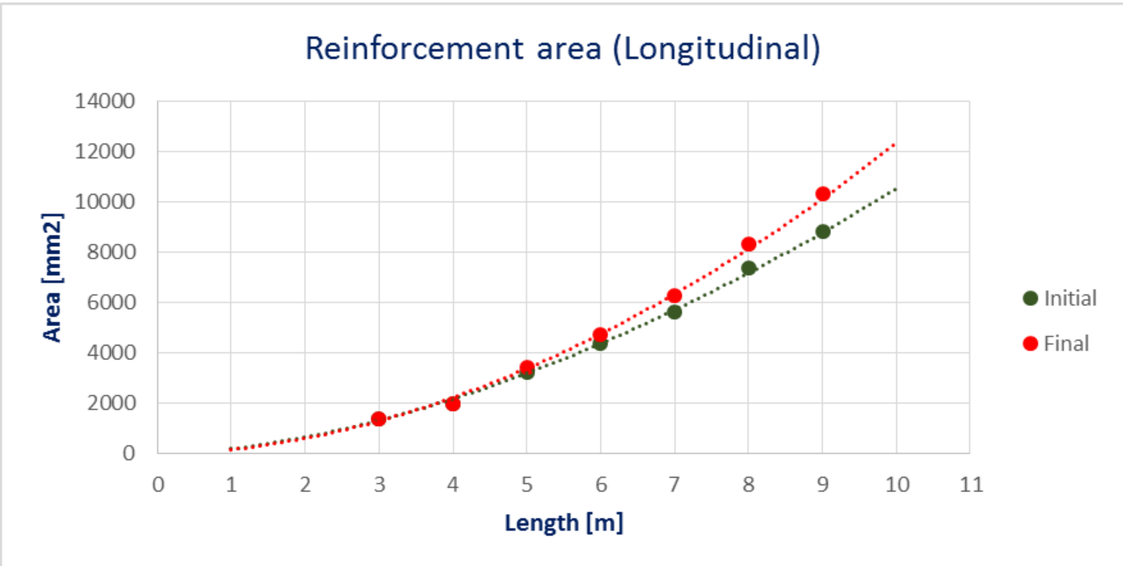


Figure 0-9 Trend of reinforcement in the longitudinal direction. Martinez Diaz (2014)

	SWEDEN		SPAIN	
LENGTH	TRANSVERSE	LONGITUDINAL	TRANSVERSE	LONGITUDINAL
3	42Ø16s71	18Ø10	45Ø16s66 56Ø16s53 (c)	19Ø10
4	52Ø16s75 58Ø16s68 (c)	10Ø16	56Ø16s71 74Ø16s54 (c)	12Ø16
5	65Ø16s75 74Ø16s67 (c)	16Ø16 17Ø16 (f)	70Ø16s71 94Ø16s53 (c)	18Ø16
6	78Ø16s75 92Ø16s65 (c)	14Ø20 15Ø20 (f)	84Ø16s71 112Ø16s53 (c)	16Ø20
7	84Ø16s83 110Ø16s63 (c)	18Ø20 20Ø20 (f)	98Ø16s71 132Ø16s53 (c)	20Ø20
8	96Ø16s83 126Ø16s63 (c)	15Ø25 17Ø25 (f)	104Ø16s76 152Ø16s52 (c)	17Ø25
9	108Ø16s83 144Ø16s62 (c)	18Ø25 21Ø25 (f)	117Ø16s76 172Ø16s52 (c)	20Ø25 21Ø25 (f)

Table 0-3 Design for standard bridges with Spanish and Swedish national annexes, Garcia Rodriguez (2014), Martinez Diaz (2014)

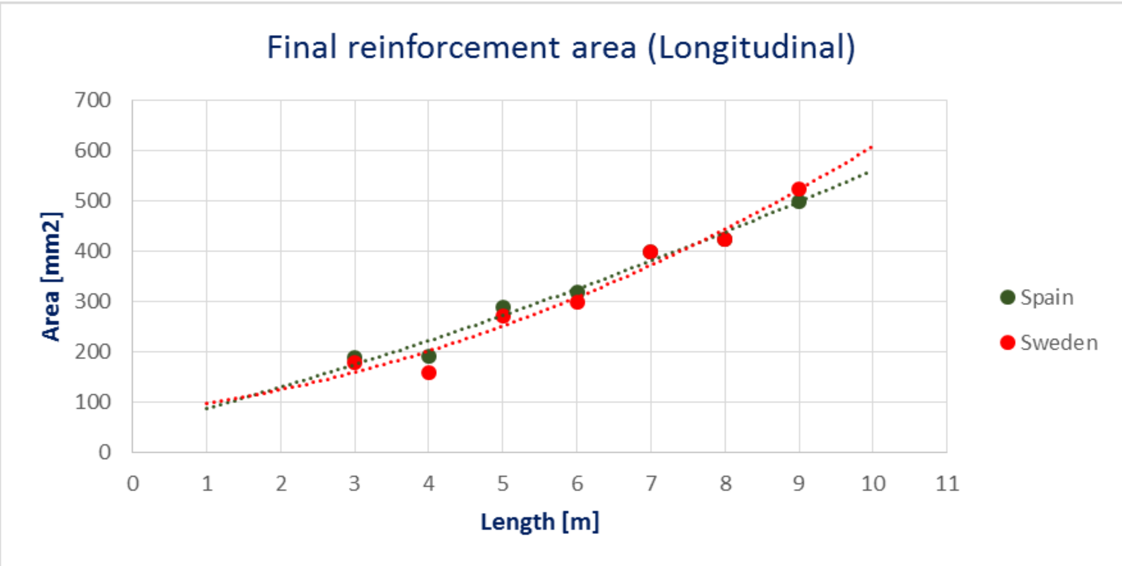


Figure B.0-10 Final reinforcement area in longitudinal direction according to the Spanish (E), (Garcia Rodriguez, 2014) and Swedish (S) National Annexes., (Martinez Diaz , 2014)

	SPAIN	SWEDEN
Classification coefficient (α)	1,21	1,33
Safety factor (γ_d)	1,10	1,00
Dynamic factor (Φ)	Φ_3=1,69	Φ_2=1,46
Load factor for SLS (ξ)	0,85	0,89
Ballast height deviation ($G_{k,sup}$)	+/- 30%	+/-10%
Load factor (LM71)	1,45	1,50
Maximum crack width (w_{max})	**0,4 mm**	0,3 mm

Table 0-4 Differences in National Annexes for Spain and Sweden, Garcia (2014), Diaz (2014)

Conclusions

The differences between the national annexes to the Eurocode for concrete bridges are quite small. It would thus be a good idea to prepare European standard bridge designs for short concrete bridges. However, it should be noted that special conditions will be present at each site regarding e.g. the foundation properties which would require that certain parts of the design are checked for each individual bridge.

B.2 Standard half and full frames for underpasses in Germany

About 50% of the railway bridges in Germany have spans ≤ 6m and about 30 % have spans between 6 and 15 m. For underpasses, Deutsche Bahn recommends standardized full frames for spans ≤ 6m and standardized half frames for spans up to 15 m, see Figure B.0-11 Deutsche Bahn (2013).

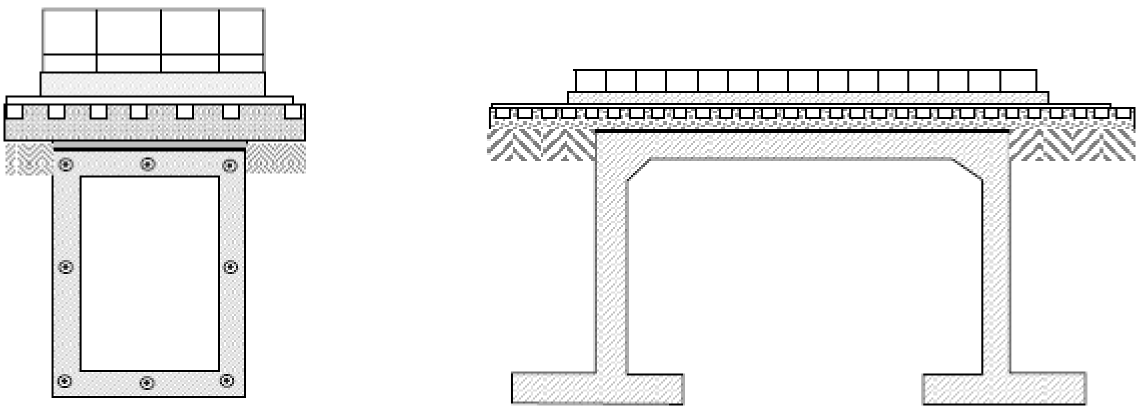


Figure B.0-11 Full frames and half frames standardized in Germany, Deutsche Bahn (2013)

The following advantages of standardized frame bridges are mentioned:

- Low production cost
- Reserve load-carrying capacity by possible redistribution of section forces
- Easy and fast exchange of bridges
- Low maintenance cost due absence of joints and bearings
- High riding comfort

The amount of reinforcement is 170 – 190 kg/m^3

For the modules there are Entscheidungshilfen (How to Choose), Check lists, Leitfaden (Things to consider), Zulassungen (Permitted solutions) and drawings

B.3 Standard bridges by Network Rail in the United Kingdom

Network Rail and its predecessors, Railtrack and British Rail, have used standard bridges since the 1950s (SCI 2004). Five designs of ”half through” steel bridges and seven designs of concrete bridges are included in the Network Rail catalogue of standard designs (which also includes standard repair details covering the most common defects found in steel and masonry bridges) and these are described below.

The standard bridges have been designed to ensure satisfactory performance of the asset under both normal operations and abnormal operations (both planned and unplanned). A further consideration has been Network Rail’s requirement to reduce the volume of maintenance and management costs through the adoption of good practice. This leads to a number key design drivers including:

- Failure modes: Critical failure modes should give warning, and alternative load paths should be provided for potential local failures.
- No hidden details: All main structural elements should be visible from at least one side.
- Robustness: It is desirable for elements of the structure to have a degree of robustness so that they are not damaged by unforeseen events disproportionate to the cause.
- Capability to support load.
- Acceptable deformations.
- Structure gauge requirements: The bridges have been designed to cater for a range of positions of the structure gauge allowing their wide use.
- Safe working environment: The bridges have been designed to minimise the risk to people on or about the bridge.
- Resistance to “bridge bash”: The bridges have been designed minimise the risk of catastrophic failure in the event of a “bridge bash”.
- Resistance to derailment: The bridges have been designed to cater for the codified derailment loads, as well as protecting the structure whilst mitigating damage to the surrounding structures.

Z type steel bridge

The Z type bridge is designed to carry a single track for spans between 6m and 17m and is a development of the earlier A type. The name of the design reflects the section of the main girders, which are a “Z” beam, with the bottom flange offset under the deck and the top flange offset away from the deck. This arrangement permits inspection and maintenance access to the main girder webs from the underside on multiple track bridges where individual spans for each track are placed immediately adjacent to each other.

The standard Z-type deck comprises a single track half-through deck with two z-shaped steel main girders and either a filler beam floor or a steel floor. The main girders are simply supported on short rocker bearings. Trimmer girders are supported on the inside edges of the main girder bottom flanges.

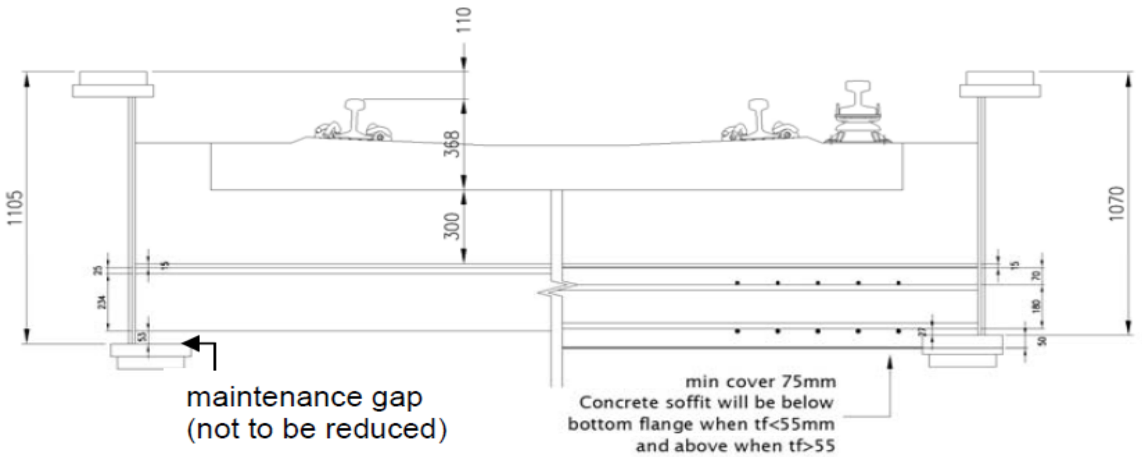


Figure B.0-12 Representative cross section of the NR Z type bridge

There are two Z-type floor arrangements, a filler beam floor option and a steel floor option. The filler beam floor option is suitable for the majority of schemes with the exception where lifting weights or the loads on existing abutments are to be minimised. In this situation, the steel floor option is advantageous at the detriment of the construction depth which is greater than the equivalent filler beam floor. Figure B.12 shows a split cross section of the shallow main girder design with a steel floor (left) or filler beam floor (right). (Network Rail 2010 A);

U type steel bridge

The U type is a development of the Z type, designed to reduce maintenance issues and construction depth, and is considered suitable for spans between 4m and 20m.

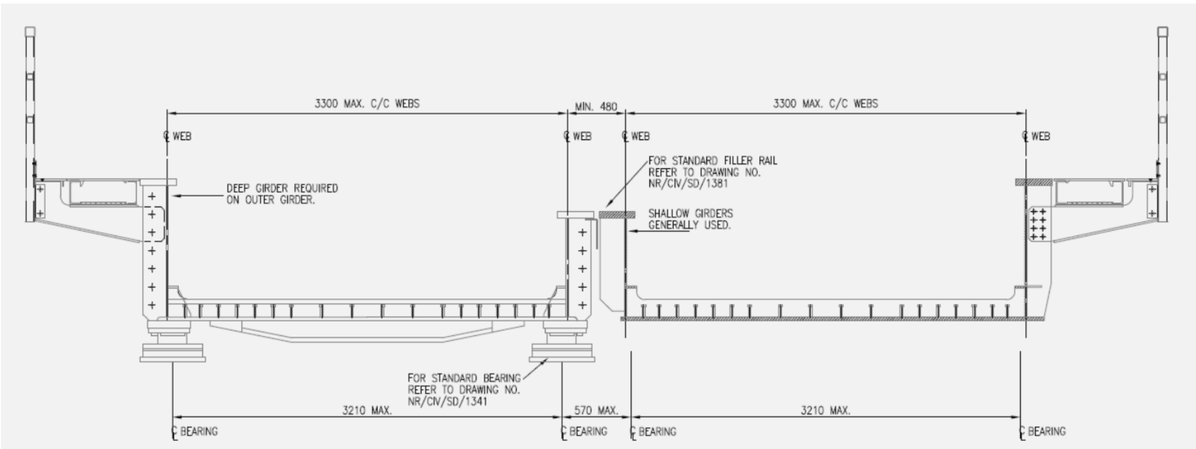


Figure B.0-13 Split cross section of the NR U type bridge

The U-type deck comprises a single track half through structure comprising a full width steel floor plate stiffened transversely, acting compositely with a concrete slab cast on top and a pair of main girder webs with offset top flanges. The deck is simply supported on short rocker bearings. Trimmer ribs are integral with the bearing stiffener for 0^{O} – 25^{O} skews and independent, supported on the deck plate, for skews greater than 25^{O}. (Network Rail 2010 B)

D type steel bridge

The D type deck is designed to carry a single track over a span range of 12m to 30m at skew angles between $0^{O}$and 50^{O}.

The D-type deck comprises a half-through deck with two I-shaped steel main girders and either a filler beam, composite or a steel floor, having minimum construction depths ranging from 882mm to 1198mm. The main girders are positioned within the platform gauge and simply supported on either line rocker bearings or spherical bearings (at obtuse corners of 25^{O} to 50^{O} skew decks). Trimmer girders are supported on the inside edge of the main girder bottom flanges for skews up to 25^{O}, and spherical bearings for all skews from 25^{O} to 50^{O}.

In all cases, it has been assumed that the D-type deck will be constructed offline and lifted, slid, jacked or moved into its final position using self-propelled lifting vehicles. (Network Rail 2010 C)

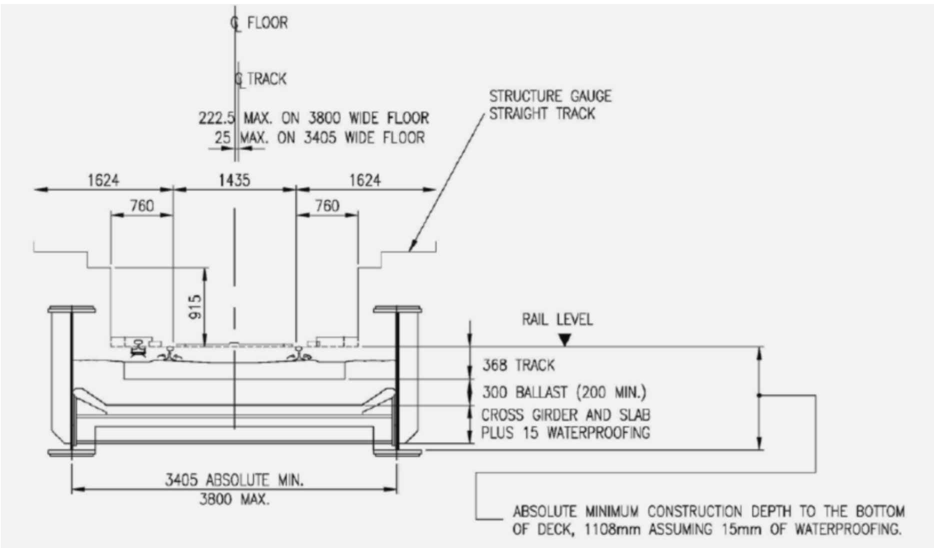


Figure B.0-14 Cross section NR D type bridge with filler beam floor.

E type steel bridge

The E type deck is designed to carry two tracks over a span range of 12m to 30m at skew angles between 0^{O} and 50^{O}.

The standard E-type deck comprises a half-through deck with two I-shaped steel main girders and either a filler beam, composite or a steel floor, with construction depths ranging from 1118mm to 1283mm. The main girders are positioned within the platform gauge and simply supported on either line rocker bearings or spherical bearings (at obtuse corners of 25^{O} to 50^{O} skew decks). Trimmer girders are supported on the inside edge of the main girder bottom flanges for skews up to 25^{O}, and spherical bearings for all skews from 25^{O} to 50^{O}.

In all cases, it has been assumed that the E-type deck will be constructed offline and lifted, slid, jacked or moved into its final position using self-propelled lifting vehicles. (Network Rail 2010 D)

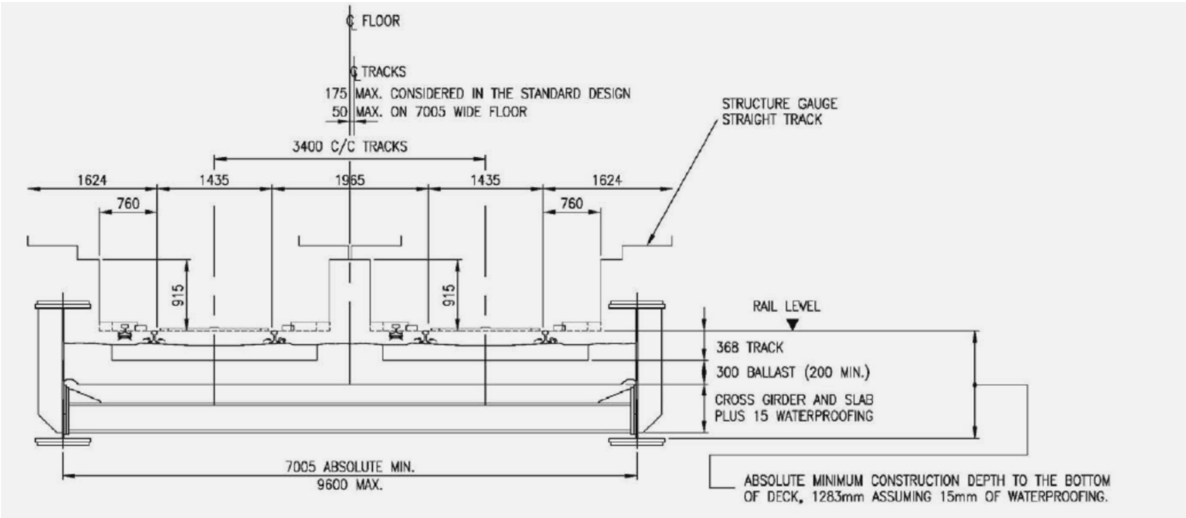


Figure B.0-15 Cross section NR E type bridge with composite floor.

Box girder steel bridge

This design caters for three deck arrangements and spans from 18m up to 39m:

- double track two girder arrangements (from 21m to 39m in 3m increments),
- double track three girder arrangements (from 21m to 27m in 3m increments)
- single track two girder arrangements (from 21m to 27m in 3m increments).

The 21m span box section is intended for use for spans down to 18m, or for shorter spans if other forms of underbridge are not suitable.

The box girder form of underbridge is particularly advantageous for skew ended decks; this is due to the shear plate connection between the deck and the main box girders that allows a degree of rotation. However, track twist criterion limits skew angles to 55°. For the double track two girder bridge arrangement, two floor widths - "narrow" (6750 mm maximum) and "wide" (8600 mm maximum) - are available, depending on track geometry and depth of main girder. For the double track three girder or single track two girder bridge arrangements, the floor width is a maximum of 3200 mm. There is also a double track “shallow narrow” floor (6900mm maximum) for use in an alternative deck arrangement to double track three girder bridges, or where construction depth is particularly limited.

The bridge concept is a half through deck comprising trapezoidal box girders and a Tee-rib stiffened plate deck. The box girders are proportioned to achieve the shortest possible floor span whilst located within the platform clearance of the standard structure gauge. The inclined inner face of the girder retains the track ballast via ballast plates and supports a steel floor of minimal depth consistent with requirements for strength, including fatigue, and stiffness. All inner webs are sloped at 3 (horizontal) to 25 (vertical). The floor is steel with transverse spanning ribs, generally cut out of rolled UB sections, welded to the deck plate. The main girders are simply supported on fabricated line rocker bearings. Trimmer girders are supported on the inside face of the box adjacent to the main bearings, except for higher skews when the trimmer is supported on bearings direct to suit the width of floor panels. Provision is made for low headroom bridges over highways for which vehicle collision restraint devices are detailed.

Walkways, with parapets, are cantilevered from the main girder outer webs and can incorporate a cable route to support services.

Permanent access for inspection (and tightening connections at time of construction) is provided through a hinged door in the end diaphragms of the main girders. A minimum number of intermediate diaphragms, with an access for inspection, are provided within the box girders consistent with the need to reduce warping and distortion stresses and to assist in fabrication. (Network Rail 2010 E)

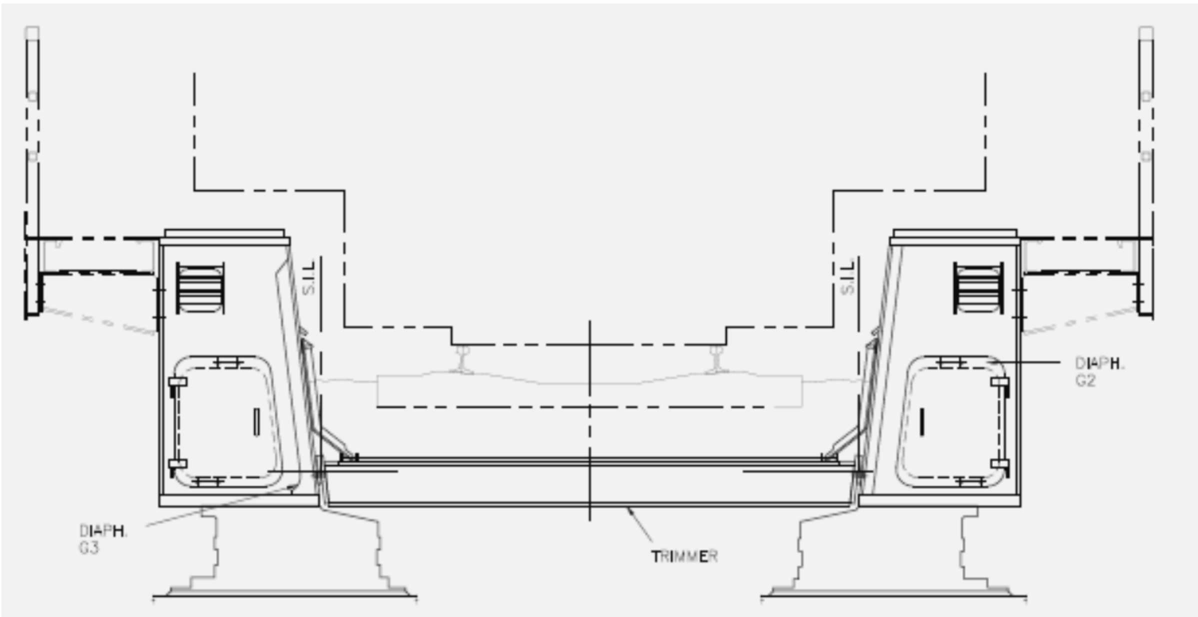


Figure 0-16 End elevation of NR single track box girder bridge.

Concrete bridges

The standard concrete underbridge designs illustrated in Figure B.17 provide a complete set of preferred details for a range of concrete deck forms and cill beam (illustrated in Figure B.18) arrangements. These bridges are generally applicable for spans between 2.5m and 20m for a range of skews up to 50°. It is acknowledged that certain deck forms can be taken beyond these limitations, but their use is not often exploited as the increased weight and construction depth are generally prohibitive and other deck forms are often adopted for spans over 20m.

The standard concrete forms comprise single, double or multiple track deck type longitudinal spanning arrangement of reinforced concrete, filler beam or pre-stressed solid box beam construction. All options can be pre-cast off site and transported from the shop in manageable sections and assembled on site in their final position which should be suitable for the majority of schemes. Alternatively, should there be a longer period over which the railway is blocked then options for cast on site have been provided, noting that these would also apply to constructing immediately offline and transporting into position during a possession.

The selection of the preferred deck arrangement is dependent upon many factors and Figure B.18 highlights the key constraints to each of the deck types. Two variants to the filler beam have been detailed with the encased sections being preferred. The alternative exposed bottom flange arrangement is often utilised where construction depths do not permit the fully encased option and also the arrangement lends itself to being erected piecemeal allowing formwork to span between bottom flanges eliminating the need for significant false work to construct.

The preference would be to reduce the number of joints within the deck but is recognised that this is not always possible due to the various site constraints.

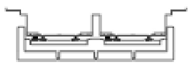
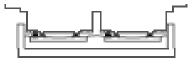
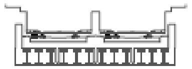
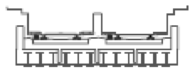
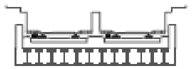
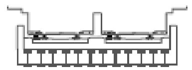
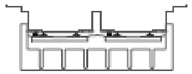
Deck Type							
Description	Segmental Reinforced Concrete Slab	Reinforced Concrete Slab	Segmental Fully Encased Filler Beam Deck	Segmental Exposed Bottom Flanges Filler Beam Deck	Fully Encased Filler Beam Deck	Exposed Bottom Flanges Filler Beam Deck	Pres-stressed Solid Box Beam
Typical Span Range	Up to 6m	Up to 6m	Between 5m and up to 15m	Between 5m and up to15m	Between 5m and up to15m	Between 5m and up to15m	Between 10m and Up to 20m
Typical Skew Range	Up to 50°	Up to 50°	Up to 50°	Up to 50°	Up to 50°	Up to 50°	Up to 45°
Typical Depth of Section	1 in 10 short span 1 in 18 long span	1 in 10 short span 1 in 18 long span	1 in 15 short span 1 in 25 long span	1 in 15 short span 1 in 25 long span	1 in 15 short span 1 in 25 long span	1 in 15 short span 1 in 25 long span	1 in 18
Typical width Range	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
Deck Joint Selection	No connection for spans < 6m (refer to 4.7.1 for limitations) Shear connection Post tensioned for skews less than 10°	N/A	No connection for spans < 6m (refer to 4.7.1 for limitations) Shear connection for spans >6m Post tensioned for skews less than 10° and >6m	No connection for spans < 6m (refer to 4.7.1 for limitations) Shear connection for spans >6m Post tensioned for skews less than 10° and >6m	N/A	N/A	Shear connection
Cill Unit Selection	All Types Type 1A (preferred)	All Types Type 1 (preferred)	All Types Type 1A (preferred)	All Types Type 1A (preferred)	All Types Type 1 (preferred)	All Types Type 1 (preferred)	Type 2, 2A & 2B Type 2A (preferred)

Figure B.0-17 NR's standard concrete bridge designs.

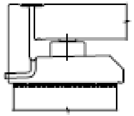
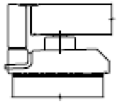
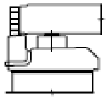
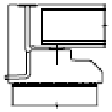
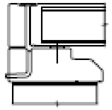
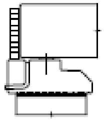
Cill Type	**Type 1**	**Type 1A**	**Type 1B**	**Type 2**	**Type 2A**	**Type 2B**
						
Selection Criteria	Suited for all bridge spans and deck forms An integral ballast wall reduces the number of crane lifts and other site activities such as back fill material to can be placed immediately after cill unit / back of wall drainage has been installed. Permits variation in bearing levels (skew decks) by altering plinth heights Cill Holding down restraints in between plinths can be post grouted after deck installation. Provides good access to drainage Option to chamfer leading edge to improve access	Generally as Type 1 but provides flexibility and more tolerance on placement of deck Permits access to rear of deck to install longitudinal stitch reinforcement and installation of cementitous material Introduces additional ballast wall to cill dowelling activity during the possession. Permits access to rear of bearing during deck placement. Level of ballast wall can be marginally adjusted to suit line and level that deck has been placed.	Suited for bridge spans of small movements (spans of 6m or less). Suited for use with sheeted membrane Permits access to rear of deck to install longitudinal stitch reinforcement and installation of cementitous material	Suited for all bridge spans and deck forms Lateral restraints to be installed at the same time as deck installation.	Suited for all bridge spans and deck forms Permits access to rear of deck to install longitudinal stitch reinforcement and installation of cementitous material Lateral restraints to be installed at the same time as deck installation.	Suited for bridge spans of small movements (spans of 6m or less). Suited for use with sheeted membrane Permits access to rear of deck to install longitudinal stitch reinforcement and installation of cementitous material Lateral restraints to be installed at the same time as deck installation.

Figure B.0-18 Cill beam details for NR's standard bridges

For the reinforced concrete and filler beam decks there is the option to cast on site (final position). This approach is not common to most schemes as this would be more appropriate to a new build railway or where a lengthy closure has been granted to an existing railway line. The last option available to all deck forms would be to erect the new structure adjacent to the final position on temporary works and manoeuvred into position. Again this option is not common to most schemes, and is often not cost effective and tends to be adopted where constraints, either inherent with the site or where possessions are to be kept to the minimum that permit the whole structure to be removed and installed within a short period.

The preference is to have an integral deck but it is recognised that in some instances this is not achievable. Having individual units placed alongside one another with no shear connection introduces differential movement between adjacent units, especially on a multiple track railway line where one line is loaded and the adjacent line is not. The magnitude of this differential movement is a function of the span and stiffness of the deck units and it is recommended that spans over 6m should have shear connected decks unless it can be demonstrated otherwise that this differential movement reduced or alternatively accommodated between decks. The individual pre-cast off site concrete units for the three alternative deck forms should be preferably shear connected together by an in situ cementitious stitch. If possession constraints are such that there is insufficient time available to prepare the stitch and subsequently fill with a cementitious material, the joint should either be transversely post tensioned to permit the transfer of load between joints or in some cases a nominal gap can be maintained between adjacent units. (Network Rail 2010 F).

Appendix C. Possession Cost Examples

C.1 General

In this Appendix a method is presented on how to make a simple estimation of possession costs. As an introduction some notes are given on how possession costs are calculated in some countries.

C.2 Cost used in Great Britain

Methods to estimate possession costs were introduced in the 1990s with the privatisation of the rail network. The way the possession costs are calculated has then been gradually refined and is today rather complex. The main ideas will be outlined below, ORR (2008, 2011a.b, 2012a, 2013), Lloyd's (2012).

Possession costs are agreed for each five-year Control Period (CP). The latest period, CP5, started on 1April 2014. The possession costs are part of overall track access charge negotiations. There are two kinds of compensations: Schedule 4 and Schedule 8. Schedule 4 compensates train operators for the impact of **planned** service disruption due to possessions, whereas Schedule 8 compensates for **unplanned** service disruption due to poor performance. Compensation is intended to cover fare revenue losses, and costs, such as those associated with running replacement buses.

The payment RP is calculated as the delay in minutes times a cost/minute factor according the formulae, ORR (2011a, b):

$$RP = \sum\left(\left(WACM + NREJT\right) \bullet BF \bullet MRE \bullet NF\right)$$

RP is the Rail Payment to train operators (GBP)

WACM is the weighted average of Cancellation Minutes (minutes)

NREJT is the extended Journey Time as a result of Rail Restriction of Use (minutes)

BF is a busyness factor (-)

MRE is a marginal revenue effect (-)

NF is a Notification Factor (GBP/minute) usually of the order of 20 to 80 GBP/minute depending on the importance of the route, time of day and the volume and types of traffic being carried (≈25 Euro/minute to 100 Euro/minute), ORR (2013).

As an example a 72hr possession on the East Coast Mainline had a possession cost of £2.4million. Here all tracks were blocked on one of the busiest lines for two miles near Finsbury Park station and it was arranged more than one year before the work. With four parallel tracks it corresponds to a cost of about

2,400,000*1,25 / (4* 72* 60) ≈ 175 Euro/minute/track.

From the start of CP5, these costs will be increasing again, which gives a good incentive to reduce the number of possessions that are requested, by planning and designing works to require fewer disruptive closures.

Cost of speed restrictions are also relevant when track work and embankment remediation is being carried out. As an example can be mentioned one of the Network Rail sites on the East Coast Mainline in Scotland that was affected by mining subsidence. The cost of speed restrictions was here for an extended period of nearly two years about 20 M€ (£16million) and almost matched the cost of the remediation work.

C.3 Cost used in Austria

In Austria track passion costs has been studied at the University of Graz, EBW (2011). Some results are presented in Table C.1. The cost ranges between 1 and 40 Euro/minute depending on line and time.

Track Load kton/day	Time Span	30 min	45 min	1 h	2h	4 h	6 h	8h	24 h	44 h	54 h	216 h	384 h
> 70	Day	336	434	918	1,430	3,552	5,608	7,483	51,091	92,094	118,489	387,190	712,407
	Night	394	761	1,366	3,388	7,678	13,368	20,789					
	Weekend									60,619	85,821		
45 – 70	Day	338	442	842	1,729	3,884	6,459	9,479	36,621	64,073	82,223	265,351	486,150
	Night	391	670	926	2,293	4,716	8,611	11,380					
	Weekend									53,895	64,073		
30 – 45	Day	210	521	987	2,412	6,697	9,210	11,290	32,705	58,766	71,795	252,025	460,405
	Night	166	208	346	1,905	4,629	8,239	11,705					
	Weekend									56,060	58,766		
15 – 30	Day	194	316	402	1,068	2,009	4,022	5,584	19,359	36,220	44,518	148,366	272,806
	Night	202	484	887	1,854	2,822	5,261	6,707					
	Weekend									30,161	36,220		
8 - 15	Day	264	550	814	1,836	3,475	5,276	6,068	15,143	27,460	30,951	101,837	188,994
	Night	0	34	66	66	66	159	1,069					
	Weekend									13,808	16,546		

44 h on weekdays: Tue-Thu 44 h on weekends: Sat-Mon
54 h on weekdays: Mon-Thu 54 h on weekends: Fri-Mon
216 h: 9 Days: Sat-Mon 384 h: 16 Days (including 2 weekends)

Table 0-1 Austrian Possession costs in Euro (2007) for closure of a single line, EBW (2011).

C.4 Cost used in Sweden

In Sweden general guidelines are given for cost-benefit analysis (CBA) of transport investments but no detailed methods for rail possessions have yet been presented, ASEK (2014), Bångman (2014). However, as an example can be mentioned that disturbances in the traffic around Stockholm in the period May 25-30, 2012, was estimated to give costs to the society of about 6.7 M€ (62 MSEK) according to Table C.2, TRV (2012).

Costs MSEK		**May 25**	**May 27**	**May 29**	**May 30**	**Sum**
Delayed person trains	Cost for passengers	22	3	14	18	**57**
	Costs for vehicles	1	0.3	1	2	**3**
Delayed freight trains	Costs for freight customers	0.02	0.00	0.03	0.02	**0.07**
	Cost for vehicles	0	0.00	0.03	0.02	**0.07**
Cost for bus travel etc.	Costs for extra time	-	0.07	1.3	-	**1.4**
	Costs for buses	-	0.02	0.3	-	**0.3**
Sum		**23**	**3**	**16**	**20**	**62**

Table C.0-2 Society costs for rail disturbances in Stockholm in May 2012, TRV (2012)

As can be seen the main costs are for the extra time passengers have to spend waiting. Society. According to Bångman (2014) the cost used for passenger and hour is about 6.5 -8 € (59 – 73 SEK)

Some methods used to calculate costs for road bridges have been presented in the Nordic Project ETSI (2012), also referred to in ML-D5.4 (2014), Section 7.4.3.

C.5 Example of a simplified Method

As an **example** we study a line with

1 million passengers per year per track km and

2 million freight tonnes per year per track-km.

As one year has 365*24 hours = 8760 hours, the figures above are equivalent to 114 passengers per hour per track-km and 228 freight-tons per hour per track-km.

We assume the following costs for a delay that is accidental (not planned) and with figures in parenthesis for delays that are planned one year ahead:

50 (1) € per person per hour of delay.

300 (50) € per extra bus/train per hour for 50 passengers gives 6 (1) Euros per person per hour

10 (2) € per ton and hour if a freight train has to be redirected (Alternative A)

100 (50) € per ton and hour if a freight train has to be reloaded to trucks or the entire journey for its load has to be done by road (Alternative B)

For a **possession time of 24 hours** we get the following costs if the possession could be planned one year ahead:

Passengers:

24*114 = 2,736 passengers are affected by the delay but only about half of them, 1,368, for 24 hours. This gives 24 *(1+1) = 48 €Euros per person which gives a total cost of 48*1,368 = 65.,664 Euros. However, the actual delay experienced is the difference in journey time which will depend on many factors but should not exceed 2 hours in most circumstances in GB. This would reduce the costs to 2*2 = 4€ per person which gives a total cost of 4*2,736 = 10,994 €

Freight:

24*228 = 5,472 tons are affected but only about half of them, 2,736 tons, for 24 hours

2 € per ton and hour gives 2*2,736 *24 = 131,228 € in Alternative A. However, similar to the above, in most cases freight trains will be diverted via an alternative route with a longer journey time of, say, 4 hours, which gives 4*2*5,472 = 43,776 €

Total:

Depending on how you calculate we get 65,664 + 131,228 = **196, 892** € or 10,994 + 43,776 = **54,720** € for a possession time of 24 hours planned 1 year ahead.

C.6 Example applied to Turkish conditions

A summary of Turkish possession costs are given in Table C.3. Some general facts of the Turkish net is first presented:

Total Length, km	12 008
Million Passengers per year per track-km	5
Million Freight-tons per year per track-km	11 670
Passenger Revenue for 2012 € (1 Euro =2.94 TRY)	69 847 900
Passenger Revenue, € per person per hour	11.1
Freight Revenue for 2012 € (1 Euro =2.94 TRY)	198 994 296
Freight Revenue, € per ton per hour	0.0124
Passenger Revenue for 2012 TRY, Turkish Lira	205 352 825
Freight Revenue for 2012 TREY, Turkish Lira	58 5043 229

Table C.0-3 Calculation for possession of 1 km of track (source TCDD)

Possession time, hours	**24**	**48**	**72**	**24**	**48**	**72**
Preparation time, years	**1**	**1**	**1**	**5**	**5**	**5**
	Short time planning			**Long-time planning**		
Cost for passengers						
Per person per hour of delay, Euros	28	28	28	11	11	11
Bus/train per hour and 50 passengers, Euros	50	50	50	50	50	50
A. Cost for a delay of 2 hours, Euros	30 134	30 134	30 134	12 683	12 683	12 683
B. Cost for a delay of 4 hours, Euros	60 267	60 267	60 267	25 367	25 367	25 367

Cost for freight						
A. Reroute per ton and hour, Euro	0.031	0.031	0.031	0.012	0.012	0.012
Total cost, Euro	41 430	41 430	41 430	16 572	16 572	16 572
B. Reload per ton and hour, Euro	0.062	0.062	0.062	0.012	0.012	0.012
Total cost, Euro	82 859	82 859	82 859	16 572	16 572	16 572

Total Cost Alternative A, Euro	71 563	71 563	71 563	29 255	29 255	29 255
Total Cost Alternative B, Euro	143 126	143 126	143 126	41 938	41 938	41 938

C.7 Conclusion

It is easy to make a simplified assessment of the cost for a track possession. You start with the number of passengers and the amount of freight that will be affected. Then you estimate the costs for the delays per hour (or per minute). Here you can get a rough indication by the numbers given in the examples above but still better is if you make an educated appraisal of the costs for your railway.

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