Quality checked & approved
by project co-ordinator André Van Leuven

FINAL PUBLISHABLE ACTIVITY REPORT

CONTRACT N°	**031312**		
PROJECT N°	**FP6-31312**		
ACRONYM	**URBAN TRACK**		
TITLE	**Urban Rail Transport**		
PROJECT START DATE	**September 1, 2006**		
DURATION	**48 months**		
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Date of issue of this report	**October 15, 2010**		
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LIST OF PARTNERS

Paricitpan rolet	Number	participant name	short name	country	date enter project	date exit project
CO	1	Dynamics, Structures & Systems International	D2S	Belgium	01M	48M
CR	2	Société des Transports Intercommunaux de Bruxelles	STIB	Belgium	01M	48M
CR	3	Alstom Transport Systems	ALSTOM	France	01M	48M
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CR	9	Tecnologia e Investigacion Ferriaria	INECO-TIFSA	Spain	01M	48M
CR	10	Institut National de Recherche sur les Transports & leur Sécurité	INRETS	France	01M	48M
CR	11	Institut National des Sciences Appliquées de Lyon	INSA-CNRS	France	01M	48M
CR	13	Ferrocarriles Andaluces	FA-DGT	Spain	01M	48M
CR	14	Alfa Products & Technologies	APT	Belgium	01M	48M
CR	16	Autre Porte Technique Global	GLOBAL	Philippines	01M	48M
CR	17	Politecnico di Milano	POLIMI	Italy	01M	48M
CR	18	Régie Autonome des Transports Parisiens	RATP	France	01M	48M
CR	21	Studiengesellschaft für Unterirdische Verkehrsanlagen	STUVA	Germany	01M	48M
CR	22	Stellenbosch University	SU	South Africa	01M	48M
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CR	25	Ferrocarril Metropolita de Barcelona	TMB	Spain	01M	48M
CR	27	Transport Technology Consult Karlsruhe	TTK	Germany	01M	48M
CR	28	Université Catholique de Louvain	UCL	Belgium	01M	48M
CR	29	Universiteit Hasselt	UHASSELT	Belgium	01M	48M
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CR	38	Fritsch Chiari & Partner	FCP	Austria	01M	48M
CR	39	Metro de Madrid	MDM	Spain	12M	48M
CR	40	Frateur de Pourcq	FDP	Belgium	36M	48M

PROJECT OBJECTIVES

The general objectives of URBAN TRACK fully comply with the objectives stated for "Development of cost-effective infrastructure for light rail systems", Call 3B:

"*Objective:* *The strategic aim is to support separate projects for light and heavy rail which consider the cost-effective introduction of new high performance track infrastructure products and techniques as positive drivers in modular and interoperable rail systems. The ambition is to develop and build an integrated family of "maintenance-free" modular track infrastructure solutions which can be adapted to specific circumstances and have the benefit of standardised components. Based on real and verifiable figures of today's life cycle costs that comprise track construction/renewal costs, maintenance and monitoring expenditure, the target should lead to a substantial reduction in track infrastructure costs, with a significant increase of the availability of track infrastructure (for both heavy and light rail applications). This must be demonstrated as a result of the implementation of the projects' findings.*"

Where stated in the EC Objective above: "*The strategic aim is to support separate project for light and heavy rail* …", the URBAN TRACK project focuses exclusively on urban track infrastructure for light rail (LRT), tram and metro.

For urban rail systems (LRT, tram, metro) higher track availability (more new tracks and higher availability of existing tracks) and lower LCC, face in general one or more of following problems (different from heavy rail problems):

1. Destructive opposition of the residents to install new tracks in their neighbourhood delays required authorisations. Their resistance is motivated by following arguments:
    a. installation of new track will lead to disturbance during exploitation (noise and vibrations);
    b. commerces fear the long track installation times which hinder their exploitation and hence reduce their revenues drastically;
    c. people express environmental concerns (neighbourhood less attractive), safety concerns, property value decrease, ...

2. The investment cost of classical urban tracks is very high, e.g. for embedded tram tracks (tracks integrated in the street pavement) where also the road pavement (and sometimes sewer pipes) are to be renewed.
3. No generally accepted method exists to assess the total life cycle cost of urban track systems.
4. Track renewal methods are very cumbersome, time consuming and they require often the shut down of a complete section.
5. Functional requirements are not uniform between networks, which hinders e.g. transfer of rolling stock from one network to another, sometimes even not between different lines of the same network.
6. There is almost no standardisation in components and systems within the same network: most important urban rail operators have a large number of different track systems in their network.

7. Investment costs and maintenance costs are not always covered by the same authority. The effect of increased maintenance on global costs is in general not known. LCC driven maintenance strategies are almost not existent.

The general objective of the project is to deliver an integrated series of modular track infrastructure solutions at low cost, with no or little maintenance, high availability, constant comfort and ensuring great punctuality, all this in an environmentally friendly and safe manner. In order to reach these objectives, quality and attractiveness of the tracks have to be increased and new technologies and standardisation (harmonisation) have to be introduced in the process.

The project aims at developing five innovative new products in the urban track sector:

1. Prefabricated track modules [product/solution 1]
2. Green LRT/tram tracks [product/solution 2]
3. Embedded metro tracks [product/solution 3]
4. Alternative low cost tracks for floating slab in tunnel and at grade [product/solution 4]
5. Maintenance free interface between rail and street pavement for embedded tracks [product/solution 5]

as well as six innovative analysis methods:

1. Innovative track installation methods (new tracks) [method 1]
2. Automated track installation [method 2]
3. Fast renewal and refurbishment methods (LRT/tram) [method 3]
4. Cost/benefit analysis method for urban rail infra works (LRT/tram) [method 4]
5. Preventive and predictive maintenance for metro tracks [method 5]
6. Techniques for reducing wear in curves and turnouts (LRT/tram) [method 6]

and three innovative reference documents:

1. Harmonised standard for 'Rail Transit Track Inspection and Maintenance' (metro) [standard 1]
2. Harmonised LCC calculation method [standard 2]
3. Harmonised functional performance specifications [standard 3]

The project aims at a **reduction of the LCC by at least 25% for new projects**.

The track has to be available 100%; this means all maintenance works, if any are to be performed between vehicle passage and/or outside revenue service hours.

The project findings will be validated by integrating them at a large number of test sites belonging to the end-user partners (networks).

The URBAN TRACK project, which considers new and existing lines and as well metro, LRT as tram tracks, is subdivided in different subprojects with specific objectives. These different subprojects are fully integrated as explained in section **Error! Reference source not found.**.

SP1 – Low cost modular new track systems & fast installation methods [new lines]

SP1 focuses on LRT, tram and metro tracks for new lines and extensions of existing lines.

This SP aims at researching, developing and designing ballastless track **solutions at "system" level at lowest cost** based upon the results of the LCC analysis. These solutions integrate:

- innovative new low cost track concepts, e.g. prefabricated track modules;
- ecological concepts, e.g. "green" tracks;
- maintenance and operational strategies;

and take into account all required specific interfaces (e.g. presence of road pavement, drainage, …).

Balancing initial capital costs and subsequent maintenance costs is an integral part of the new designs (see also SP4).

For new metro tracks in tunnels, the challenge is also more specific: it is also to develop new embedded track systems which allow an easy and fast evacuation of people on the trackbed in case of emergency (safety issue), as well as tracks systems with a minimum profile ('gabarit') in order to minimise the diameter of the new tunnel. In new tunnels where floating slabs have to be installed, the tunnel diameter is governed by the floating slab track dimensions. It is of utmost importance to develop track vibration isolation solutions for metro, with the same performance as floating slabs but with much smaller dimensions. This specific research is part of the project. It will reduce tunnel infrastructure costs drastically.

SP1 further aims at researching, developing and designing **innovative track installation methods** with the aim of reducing costs and increasing speed of installation, e.g. automated installation methods.

The technological project objectives for SP1 are defined and quantified as follows:

1. to develop new low cost modular track systems and components which integrate maintenance strategies, replacement strategies (e.g. future rail renewal without braking down the peripherical track elements and street pavement), ecological concerns and operational strategies: resulting in conceptual design for all considered products/solutions.
2. to develop innovative construction methods (automation, prefabrication): the objective is to divide the global track construction time by a factor two in comparison with classical track construction.
3. to increase the attractiveness of the new tracks: better noise and vibration mitigation characteristics vs. existing classical tracks on ballast while maintaining the track stability: the objective is a reduction of 6 dB(A) of the groundborne noise and a reduction of 10 dB of the vibration levels in nearby buildings without increasing the airborne noise by using "resilient" track concepts and high absorption and by use of "green" track lanes where possible.
4. To develop embedded metro tracks in tunnels, which allow an easy and fast evacuation of people over the tracks in case of emergency. This will eliminate the need for emergency walkways at the side, reducing the diameter of the tunnel. This goes together with the development of safety exits in the front and at the rear of the vehicle.

5. To develop alternative solutions for floating slab track systems in metro tunnels and for LRT/tram tracks at grade with the aim to be able to reduce the tunnel diameter of new metro systems and to reduce the foundation depth of LRT/tram track infrastructure
6. to reduce the LCC of new tracks by at least 25% in comparison with the state of practice by:
   - reducing the material costs by at least 20%, e.g. by using standardised components;
   - reducing the overall installation costs by 30% (faster installation, less space occupation);
   - increasing the life time by at least 50%: the increase in life time is e.g. due to the use of modular systems which are prefabricated under controlled environment and result in a better quality. Application on site with averse weather conditions (water, rain, cold, heat, …) and sometimes long application and stabilisation times are thus avoided and quality and life time are improved.

SP2 – Cost effective track maintenance, renewal & refurbishment methods [existing lines]

SP2 considers as well tracks in tunnels as tracks at grade (tram and metro).

This SP aims at researching, developing and designing innovative track renewal and refurbishment methods, including automated renewal methods and techniques for extending the life of existing tracks (link with maintenance). Consideration will be given to costs, environmental aspects (dust, noise), speed of execution and continuous availability of the tracks. Special attention will be given to refurbishment methods for turnouts and rails in curves.

This SPwill deal with maintenance optimisation, linked to track monitoring (inspection).

Targeted, cost-optimised maintenance can only be achieved if as well as maintenance strategies being in place to suit given set of needs, there are technical means of establishing as accurately as possible the extend of track maintenance needed. Following question will be answered: what is the economical optimum for maintenance: when, where, how much and how to maintain.

Maintenance research will include:

- study of optimal procurement of materials (use of right materials and adopted QA program);
- study of optimal control of damaging impacts: e.g. detection of wheelflats (link with rolling stock) and rail failures;
- study of optimal monitoring of rail wear and of fatigue condition of track, including new innovative methods, sensors and systems;
- study of optimal track maintenance, including rail maintenance techniques such as grinding, recharging in curves, lubrication and rail replacement.

The objectives of SP2 are to obtain:

- innovative track renewal methods, which are at least 30% faster then the classical methods, especially for embedded tram tracks;
- optimised refurbishment methods for rails in curves and for special track work, extending their normal life with at least a factor two;
- a review of the existing maintenance strategies, those used by the end-users and those described in the "APTA" track maintenance standards in order to reduce the maintenance costs by at least 20%,

combined with an improved track quality and improved RAMS performance: establishment of a harmonised European track maintenance standard;
- extend of track maintenance needed: its quantified effect on LCC, comfort and safety;
- optimal maintenance strategies for existing tracks, including procurement of components, control of damaging impacts, monitoring and maintenance techniques (preventive and predictive maintenance schemes).

SP3 – Design & implementation of solutions at test sites

From month 18, and in function of the results obtained in the other SPs, solutions will be designed for specific topics. These will be validated in the networks of ten end-users.

3.1	Madrid (E) - Embedded metro track system in tunnels
3.2	Brussels (B) - Green tram tracks
3.3	London (UK) - Rail tracks across road traffic junctions
3.4	Sevilla (E) - Rail/road interface and finishing layer
3.5	Bremen (D) - Tram track replacement techniques
3.6	Brussels (B) - Alternative for floating slab for at grade tram
3.7	Brussels (B) - Embedded tram track in curves (wear)
3.8	Barcelona (E) - Metro in tunnel – very resilient fasteners as alternative to floating slab
3.9	Karlsruhe (D) - New installation methods for prefabricated track
3.10	Manila (PH) - Automated track quality inspection system
3.11	Valenciennes (F) - Alternative for floating slab track - Resiliently supported sleepers
3.12	Brussels (B) - Comparison of different prefabricated track systems
3.13	Reims (F) - Validation of the automatic installation of track system for metro
3.14	Lombardsijde (B) - Rail tracks in combined bus and tram lanes and in junctions
3.15	Validation of software and further development
3.16	Validation of the LCC calculation and Socio-Economic Assessment methodology by a wider European Community
3.17	Validation of SP3 test sites cases against relevant SP2 recommendations

The objectives of SP3 are to obtain:

- final detailed design of all solutions retained for the specific validations concerned;
- implementation and validation of solutions (using criteria detailed further in the proposal) in end-users networks concerned;
- validation sites for dissemination and promotion purposes.

SP4 – Life Cycle Cost (LCC) calculation

Considering that urban railway operation is characterised by the need for large initial investments and large annual budgets for maintenance/renewal activity, the systematic and controlled development of LCC strategies on a European level and their comprehensive implementation become a crucial issue for the economic sustainability of the urban railway business.

The scope and definition of the LCC include the definition of the parameters that have to be taken into account, and of the methodology to be used for determining the LCC.

This SP will result in a controlled methodology to assess the life cycle cost benefits of innovative technological solutions and facilitate joint development between network operators/infrastructure managers and the supply industry. The "deliverables" (evaluations) will enable network operators/infrastructure managers to assess the effectiveness of leading edge hardware technology in terms of track availability, safety, environment and maintenance benefits.

The outcome of the SP will allow a better understanding on how leading edge track system technologies can contribute to life cycle cost optimisation, given the project specifics.

The developed LCC methodology in combination with the software tool developed within this SPwill be used to enable the other SPs to estimate the expected LCC of their findings: Especially the proposed new methods and track systems developed in SP1 as well as the benefits of new ways of maintenance, renewal and refurbishment methods arising from SP2 have to be estimated under the LCC-aspects. Following these estimations, the methodology in combination with the above mentioned tool will help to identify and clarify the current LCC of actual installations at the chosen test-sites as well as to forecast the LCC of new installations for the on-site tests (SP3).

The objectives of SP4 are to obtain:

- a generally acceptable LCC calculation method and software tool with definition of all parameters involved for evaluating complete projects as well as for the evaluation of the introduction of innovative solutions into the network;
- validation by use of the above LCC calculation method for the solutions at the validation test sites considered in SP3;
- support the studies defined in the other SPs with relevant LCC information;
- project target verification (25% reduction of LCC) of the proposed solutions;
- a cost/benefit analysis methodology for rail infrastructure works including socio-economic aspects.

SP5 – Functional requirements

SP1 and SP2 focus on a specific area either new track construction, track renewal or maintenance. The purpose of SP5 is to identify where the axes are for improvement and for further development of track components, construction methodology and system design.

Another objective is to set the basis for further evaluation of these improvements and development that will that will result from SP1 and SP2. This objective can be achieved through the following approach:

- to define the significant parameters for identifying the level of duty conditions (loads): track characteristics and conditions, vehicle characteristics and conditions, traffic type and density.
- to identify the range of duty conditions that exists on segments of the track infrastructure of participating networks taking into account the influence of vehicle characteristics and condition and traffic density.
- to select, through consultation with network operators, those duty conditions and track parameters that could provide the most marked decreases in LCC through the implementation of improved

products and processes. In addition to the use of improved products in track renewals, the objective will also be to increase the residual life of existing track through the use of better maintenance practices.

Updated functional specifications for a track infrastructure in a new network will be made available, also based upon:

- sensitivity analysis and parametric studies which evaluate the influence of track parameters (such as gauge, gauge widening, rail type, rail support stiffness, gauge tolerance, …) on track stability, on noise & vibrations, on construction costs and on LCC in general;
- the findings in ongoing EC research projects such as CORRUGATION, INMAR, TURNOUTS, SPURT, MODTRAIN, WIDEM, SILENCE, QCITY.

The updating of these functional specifications is an objective of this SP. These specifications will be used in SP1 and SP2.

The key deliverables of SP5 are the following:

- a methodology for track and vehicle categorisation and a generic model capable of predicting the duty conditions for a range of input track, vehicle and traffic parameters;
- an identification in co-operation with the networks operators of selected stretches of tangent tracks and S&C locations where the duty conditions are sufficiently onerous to cause rapid deterioration which leads to a high frequency of maintenance and LCC;
- the development of updated functional track specifications in terms of minimal LCC.

SP6 - Consolidation & Dissemination

All project results (deliverables) will be consolidated by the project co-ordinator in close collaboration with UITP and a group of network operators (not partners in the project). Their quality will be verified by the project co-ordinator.

Dissemination will mainly be ensured by UITP (infra managers), UNIFE (industry) and the partners themselves.

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INNOVATIVE TRACK SYSTEMS

GREEN TRAM TRACKS – THE ADVANTAGES OF IMPLEMENTING VEGETATION SYSTEMS IN TRAM TRACKS

Whereas in 1950 only 4 mega cities existed, there will be about 59 mega cities in 2015 (KÖTTER 2004). Changes of the natural climate due to human activities are most distinctive in urban agglomerations. Typical characteristics are higher air pollution, accumulation of contaminants, changed water balance, loss of biodiversity and heat island effect (BÖHM and GABL 1978). Furthermore, due to the climatic change more extreme weather events are forecasted. Heat waves, in particular, are of special importance. They already result in economic losses, for instance by more cases of death, diseases as well as reduction of productivity of employees (KEMFERT 2007). But not just climatic changes are relevant in urban agglomerations. Also the risen noise level causes stress and health impairment.

An approach to mitigate those negative effects on the urban climate is the implementation of technical vegetation systems on building surfaces, as for example tram tracks. Owing to the high percentage of building surfaces in urban areas, their naturation poses a great ecological potential, which should be paid attention to, with regard to the climatic and urban development.

Demands made on Tram Track Naturations in the Modern Urban Environment

Implementation of vegetation systems in green tracks is not simply done by planting some plants in a track. Demands are made on track and vegetation system by track technology, environmental conditions, operators, the public and the city.

In the modern urban environment, a suitable vegetation system is needed using robust plants, which withstand the conditions in a tram track. They need to tolerate drought, urban pollutants, as for example heavy metals, VOC, PAH and people walking across them. The vegetation system needs to be drainable during extreme rain events but water retaining, in particular to cope with dry weather. The system has to withstand the wind-drag load of passing trams. Regarding public acceptance of the tracks, a pleasant sight all year round is necessary, as well as low emissions of noise and vibration. Especially in areas with high car traffic volume the drivability of the tracks for emergency vehicles is sensible. But first and foremost, the track is part of a technical transportation system. Thus, technical demands such as compliance of stray current standards (EN 50122-2) and safety issues are obliged to be taken care of. Furthermore, unhindered access to maintenance and accessibility for snow clearing (where needed) is required. The vegetation system has to be adapted to track conditions and local conditions. For cost effectiveness of the operators low life cycle costs are vital.

Within the EU-project Urban Track, it was the objective of the Institute of Agricultural and Urban Ecological Projects, affiliated to the Humboldt-University Berlin (IASP) to cover most of those demands. Hence, a track design was developed, of which single components and prototypes were tested in the laboratory first. The solutions were finally implemented in Brussels for evaluation. Moreover, Sedum-plants were investigated for their ecological effects on the urban microclimate.

Track design

Plants

The vegetation system dealt with within this project is an extensive naturation system using Sedum-moss pre-cultivated in plastic paver. *Sedum* is a large genus of about 500 species, belonging to the family *Crassulaceae* DC.

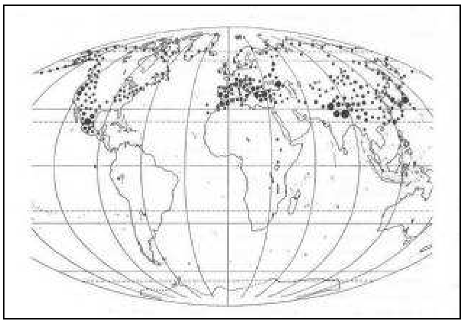


Figure 1
World distribution of stonecrops (STEPHENSON 1994)

Figure 2
Sedum track including herbaceous perennials (e.g. *Allium*), Zwickau, Germany

Most species are succulent, which means their leaves have water-retaining properties. This makes them drought resistant. They are distributed throughout the Northern hemisphere with three contrasting areas especially rich in Sedum: Mexico, Mediterranean Sea, Himalayan Mountains (STEPHENSON 1994, Figure 1). Track suitable sedum are mat-forming stonecrops. They occupy areas of rapid drainage with little competition from other vegetation. Creeping stonecrops tolerate being walked on occasionally. Any bits that break off are likely to root again. Many Sedums are frost-hardy and suitable for sunny places. Some varieties tolerate shady places. Furthermore, they tolerate air pollution. There are summer green and evergreen varieties, which flower in different colours (STEPHENSON 1994).

Figure 3
In extensive naturation systems typically used sedum plants: *Sedum sexangulare*, *S. spurium*, *S. album*, *S. floriferum* (from left to right) (pictures Schreiter)

Harmonised with the whole track system, sedum can widely be used within the Northern hemisphere. It copes well with dry periods and urban stress and has low maintenance needs, which comprise fertilization once or twice a year. Since maintenance is one of the major cost factors in life cycle costs, sedum was the choice of plant for this project. Figure 3 gives an example of sedum varieties typically used in extensive naturation systems.

Track Design

In order to allow emergency vehicles to drive on top of green tracks plastic paver was pre-cultivated with sedum. Moss settles itself over time. By means of pre-cultivation a green cover is displayed right after installation. Therefore, paver with 5 cm width was filled with 4 cm substrate. Thus, a shelter of one centimetre remains for the plants which they could regrow from in case a car drives on top of it. The substrate Xeroterr I (lava/pumice 0/12) was chosen according to tests regarding water storage capacity, drainage properties and noise absorption. Furthermore, it keeps stable over the years.

The sedum paver is placed on top of an anti root layer. This layer, if connected properly to the sides, reduces water storage capacity of the substrate and thereby guarantees that weeds cannot establish and sedum will dominate. Therefore overlapping of the anti root layer sheets is vital. At the sides the anti root layer was stapled to the rail jacket or and rubber absorber. To guarantee good drainage during heavy rain the anti root layer is a drainable fleece.

Underneath, a base layer provides stability when heavy load is applied. It is a mineral mixture 0/32 with a 1% slope towards the middle of the track and a slope outside the track, analogue, to guarantee good drainage and to avoid the development of puddles.

The rails are surrounded by a rubber jacket and placed in concrete beams (design CDM). The area next to the rubber jacket is designed in three different ways (IASP). The difference between the three solutions is the material used covering the surface of the concrete beam (see circles in Figure 4). The version on the left hand side of the picture implements a porous noise absorbing material, which is either made from drain concrete or from porous rubber (Figure 5). Both have good noise absorption properties. The version on the right hand side replaces the surface of the original concrete beam by sedum paver.

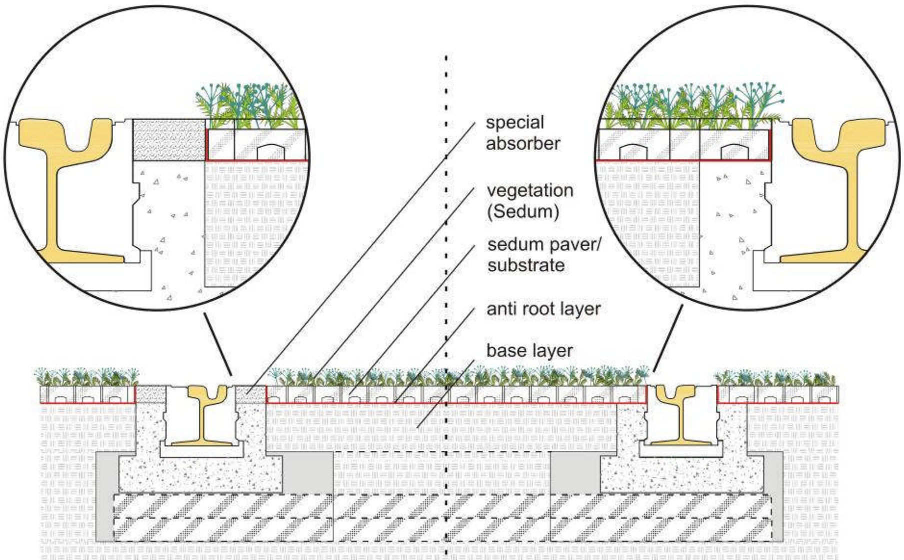


Figure 4

Design versions for Sedum track. Left: special noise absorber incorporated, Right: Sedum paver up to rubber rail jacket. IASP

Figure 5
a) Drain concrete absorber, b) Rubber absorber, c) Sedum paver up to rubber rail jacket

Figure 6
Drain concrete test body at STUVA test rig, after fatigue test

The drain concrete design was tested for fatigue at STUVA's test rig using test bodies. Simulated were vehicle crossings three times a day. The test body withstood more than 34 years simulated fatigue without damages. This is an important finding regarding the life cycle costs.

The three track design versions described above and CDM's design using artificial grass were installed in Brussels, Boulevard Leopold III, and will be evaluated for practicability, LCC and noise.

Test site Brussels

Noise absorber made from rubber and drain concrete were installed first. Prefabricated rubber absorber were glued onto the concrete beam. Drain concrete was poured and compressed on site. 550 m² of sedum paver and anti root fleece were pre-cut to the desired track dimension. This way a fast and easy installation of the fleece and the paver were possible. The fleece was stapled to the rubber sides.

The track at this area is not meant to be driven on. So underneath the fleece no base layer was installed but gravel. Although the paver would cope with heavy load, the underground is not made for it in this case.

Figure 7
Left: delivery of the pre-cut sedum paver, Middle & Right: fleece stapled to rubber absorber, installation of sedum paver

Figure 8 Sedum version is comparison. Left: rubber version, Middle: sedum paver, Right: drain concrete

Figure 9 Brussels. The four test zones in comparison. Right front: artificial grass, Left front: drain concrete absorber, Left back: rubber absorber, Right back: sedum paver

Noise reduction

Problem – Urban Noise Pollution

Noise can affect human health negatively. It can cause short- and long-term health problems, as for example cardiovascular effects, poorer work and school performance, hearing impairment, aberrations in social behaviour such as aggressiveness and passivity or immune system problems (WHO 2010, HARALABIDIS *et al*. 2008). The WHO guidelines for night noise recommend less than 40 dB (A) of annual average (Lnight) outside of bedrooms to prevent adverse health effects from night noise. According to a European Union (EU) publication: about 40% of the population in EU countries is exposed to road traffic noise at levels exceeding 55 dB (A), 20% is exposed to levels exceeding 65 dB(A) during the daytime, and more than 30% is exposed to levels exceeding 55 dB (A) at night (WHO 2010).

Traffic is human made. It is an important economic sector. Moreover, it is a major noise-emitting source. Also trams have their share to urban noise emission. Usually the rolling noise is the determining factor when it comes to emission levels from trams at speeds of between approximately 30 km/h and 40 km/h. Thus, the sound emitted horizontally to the side (and under the vehicle) is the only type remaining (KRÜGER and MARTINI 2010a, WIJNIA 1988).

Approach – Mitigation by Tram Track Greening

The whole track design

While the whole tram track design influences its noise absorption, the absorption capacity of track surfaces impacts significantly on the volume of noise emissions. A vegetation system in the tram track can reduce the reverberant parts of the track. Yet, at a green track design where the vegetation system level is at base of rail, noise is reflected from concrete beams and the rail itself. Thus, this type of green track can even have a higher noise emission compared to ballasted tracks. In measurements of KRÜGER and MARTINI (2010b) a grass track, where the vegetation system reached up to about top of rail (tor) level, achieved a noise mitigation of 2 – 4 dB (A) compared to ballasted tracks. FÜRST (2010) also investigated a grass track at tor-level (type Kassel/Dresden), and found a difference of even up to 7 dB (A) compared to ballasted tracks.

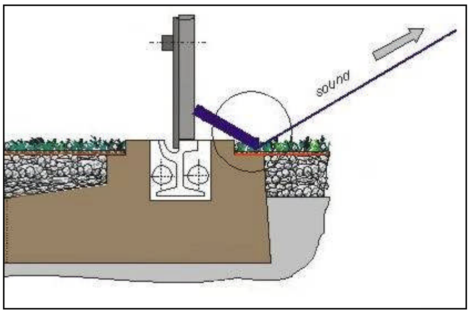


Figure 10
Noise absorption of lateral sound radiation from rail-wheel contact (IASP)

Influence of the substrate

Single components of the track design can have an essential influence on the behaviour of the overall system. Therefore the growing medium Xeroterr with two different grit sizes was compared in the laboratory, by means of an impedance tube (Kundt's tube of Brüel & Kjær, type 4206, Software BZ 5050) to obtain the sound absorption coefficient in a frequency range between 16 Hz and 1,6 kHz. Xeroterr I with a grit size of 0 to 12 mm and Xeroterr II with 0 to 8 mm is a low-organic / high-mineral growing mix composed for extensive vegetation systems and made of composted organic matter and lightweight porous lava/pumice. The test set-up within the tube reflected the layers within an extensive vegetation system in green tracks. In the tube, a space of 10 cm was adjusted. The diameter of the tube was also 10 cm. 6 cm of grit (2/11) were filled into the tube, covered by a foil (0,5 mm) and filled with 4 cm of substrate to the top of the tube. Grit and substrate were compressed each after filling.

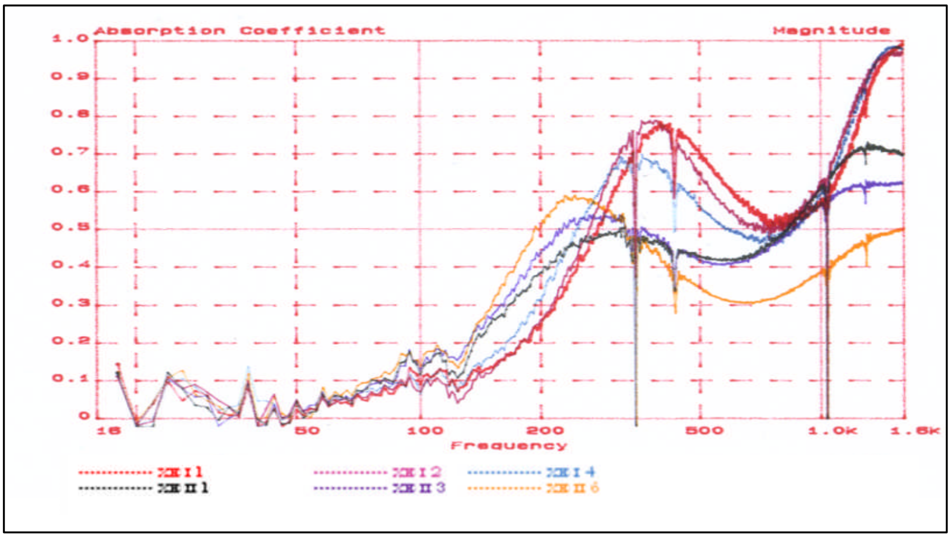


Figure 11
Comparison of sound absorption of Xeroterr I 0/12 mm (XE I, red, pink, blue) and Xeroterr II 0/8 mm (XE II, black, lilac, yellow)

As Figure 11 indicates, Xeroterr I predominantly showed better sound absorption in frequencies above 300 Hz. Maximum peaks of Xeroterr I were at 400 Hz and at 1,5 kHz, at which the absorption coefficient differs by more than 0,2. Between 800 Hz and 900 Hz Xeroterr I and II absorb relatively similar. What became clear is that the choice of the grit size has a big influence on the sound absorption. However, sound absorption is influenced by the water content. Higher water content reduces the pore volume, and thus reduces absorption capacity of the substrate.

Comparison of different track designs by means of test bodies

To replicate propagation of sound from rail vehicles, the following test rig was used to compare sound absorption of different track surfaces. Test bodies were assembled in the yard of Studiengesellschaft für Unterirdische Verkehrsanlagen (STUVA, Cologne, Germany). Pairs of identical test bodies were arranged one behind the other such that the resulting propagation area was approximately 5 m. The sound was projected across this area. On one side, a loudspeaker simulated the rolling noise while on the other the incoming noise level was measured at various measurement points positioned at different heights above and at different distances from the side of the track (see Figure 12). A special net forming a measurement-point 'grid' was positioned to ensure that the same points were used to measure each of the different test bodies. A noise signal (pink noise) provided the excitation. Both noise intensities and sound pressure levels were measured during a period of 16 seconds.

Measurements were recorded on the following test bodies (track surfaces) (KRÜGER and MARTINI 2010c): 1. artificial grass; 2. concrete paving (test bodies 15 and 16); 3. asphalt (test bodies 3 and 4); 4. paving with fixed joint connections (test bodies 9 and 10); 5. concrete with a paving structure (test bodies 13 and 14); 6. ballasted superstructure (subsequently assembled in empty steel formwork and also filled to the crown of the rail); 7. sedum without greenery; 8. sedum with greenery: sedum sprouts were distributed across test body no. 7 and measured when they rooted, a couple of weeks later.

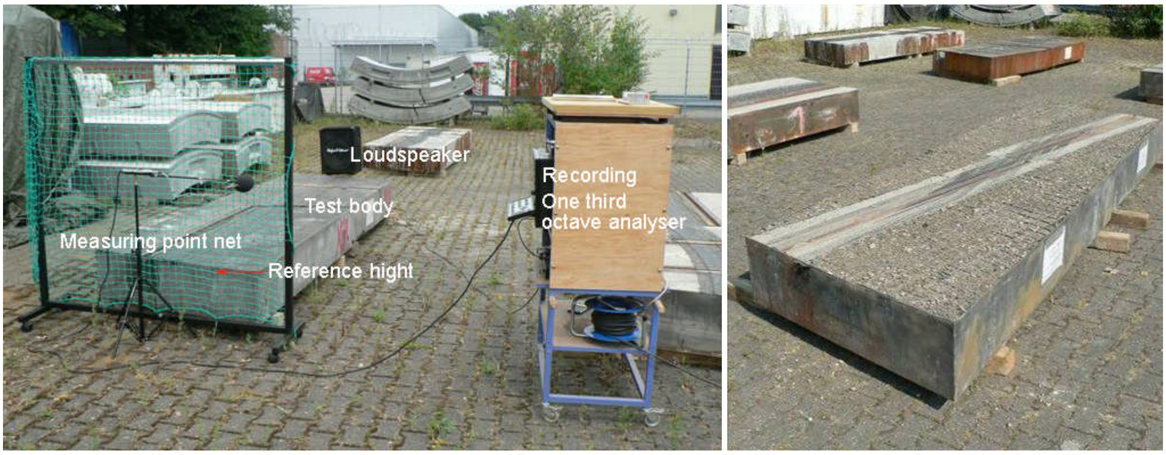


Figure 12

Arrangement of the sound absorption measurements; Left: Concrete test bodies, loudspeaker, measurement-point grid with one microphone, signal recorder and signal analyser; Right: Test body drain concrete noise absorber next to rail with sedum paver (with Xeroterr I, no Sedum plants)

An energetic mean value was produced for every measurement level and then referenced to a hard track surface (test bodies 1 and 2). Figure 13 reflects level one out of three. Absorbent rail surfaces were artificial grass, ballast, sedum paver with drain concrete without greenery and sedum paver with greenery. Different differential levels were recorded at each of the three levels.

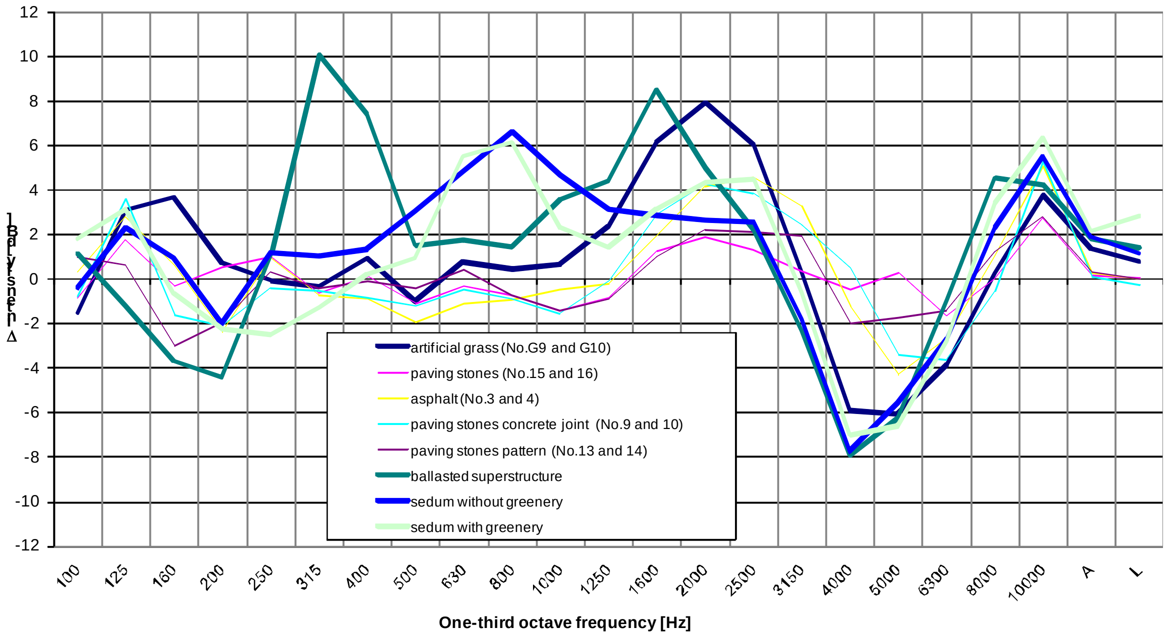


Figure 13

Differential absorption levels in relation to a hard concrete surface, level 1

Level 1 (21 cm above test body): At this level, there is a clear absorbing effect between the thirds at 250 Hz and 3 150 Hz. However, the effect is very different at each of the thirds. Noteworthy is the drop at the thirds between 4 000 Hz and 6 300 Hz. The two thirds at 8 000 Hz and 10 000 Hz are absorbent in all rail surfaces. The overall sound-reduction effect is approximately 1 to 2 dB. One extraordinary finding is the reduction of 315 Hz achieved with artificial grass and of 800 Hz with sedum paver without plants and sedum paver with plants.

Level 2 (55 cm above test body): At this level, the drop recorded for green tracks is shifted towards the thirds at 1 250 Hz to 2 000 Hz. Once again, the effect in all rail surfaces was less clearly defined in the thirds at 2 500 Hz and higher, and absorption levels for green tracks were significant between 250 Hz and 800 Hz. Again, artificial grass can be seen as the most absorbent surface at 250 Hz, while sedum paver without plants and sedum paver with plants are most efficient at 630 Hz. The overall sound-reduction ranges between 1 and 2 dB.

Level 3 (82 cm above test body): At this level, there is no clear drop in the curve for green track surfaces. The high absorption level of artificial grass is again very pronounced at 315 Hz as is that of sedum paver without and with plants in the vicinity of 630 Hz. Although at 800 Hz and higher, the effect of the various rail surfaces is negligible, the general trend is towards greater absorption on the part of green tracks. At this level also, the overall positive effect of green tracks is 1 to 2 dB. Figure 14 summarises the analyses of these measurements and gives the total differential levels averaged across all measurement. All tracks tested using the test bodies in question were of the high-vegetation variety.

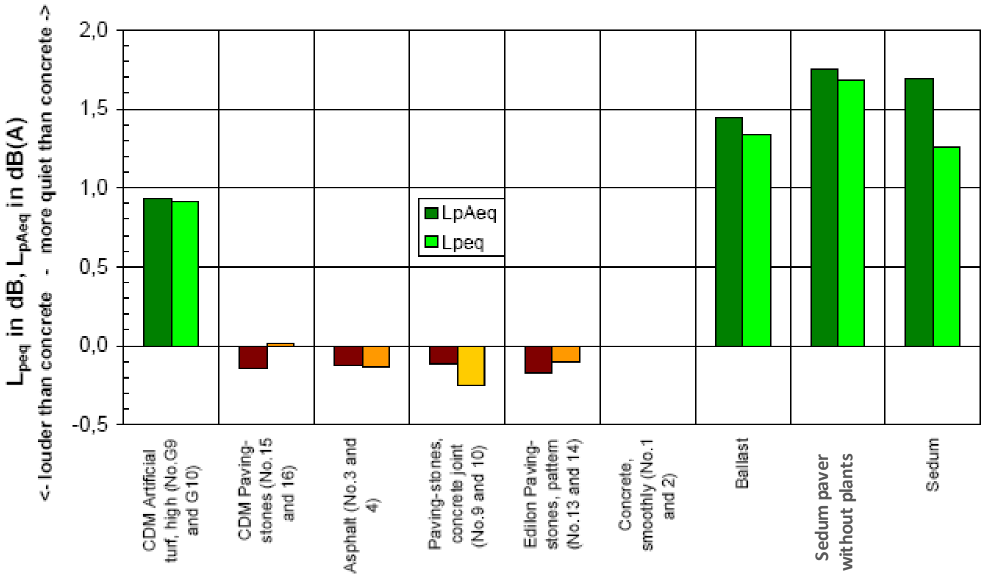


Figure 14

Differential absorption levels in relation to a hard concrete surface (combined level)

Finally, it is also mentioned in literature that green tracks seem to have a psychoacoustic effect on humans. The sheer presence of green tracks causes the feeling of a reduced noise emission.

Fine dust

Problem – Polluted Urban Air

Fine dust is a heterogeneous mixture of small aerosols coming from anthropogenic and natural sources like traffic, heating and industry. Thus higher air pollution occurs in urban agglomerations. Often polluted air of cities can be exchanged only insufficiently due to type of buildings and topography of cities in valleys, consequently pollutants accumulate.

The main focus of government and research is particles which are taken up via respiration. Particles of interest are below 10 µm (PM_{10}) and 2,5 µm ($PM_{2.5}$). The smaller the particles are the deeper they go into the lungs and the more they are absorbed by the body. The harmfulness of the dust depends on the size of the particles, its chemistry and physic. It can cause respiratory diseases, heart and cardiac diseases and even cancer.

Approach – Mitigation by Tram Track Greening

Fine dust deposits on vegetation systems where it is partly bound and accumulated. From there it can also be washed off by precipitation. Dust resuspension in vegetation systems is reduced because particles are bound to plants and soil and due to a reduced thermal. Some gaseous pollutants as for example PAH are taken up via leaves (ST-AMAND 2009). Some substances are taken up via roots, stored in the plant and can become part of the soil again after leaf fall.

No values were published so far, which express the effect of green tracks as pollution filter. It can be assumed though that on the long-term pollutants will accumulate. Within the EU -project Urban Track chemical as well as optical investigations were done with sedum coming from a tram track in the city centre of Berlin.

Chemical analysis of Sedum album from tram tracks

Sedum album from a green track next to a busy road was compared to sedum from a backyard 3 km away. PAH and heavy metals were analysed in biomass of the plants and in a substrate by means of Gas chromatography-mass spectrometry (GC-MS) and inductively coupled plasma optical emission spectrometry (ICP-OES).

Sedum album from the tram tracks showed elevated concentrations of Fe (5300 mg/kg TM), Mn (110 mg/kg TM) and Cu (40 mg/kg TM) compared to the reference plants (540 mg/kg TM, 34 mg/kg TM and 16,6 mg/kg TM). The PAH-concentration was double as high in the plants from the track (1,870 mg/kg dry matter) as in the reference (0,989 mg/kg dm). This chemical composition complies with results from LORENZO *et al.* (2006), GEHRIG *et al*. (2007) and BUKOWIECKI *et al.* (2007) where these elements dominated in the PM_{10} of the air next to a track for electrically driven trains. Main source is thought to be abrasion of brakes, wheels, rails and overhead wires. As Figure 15 displays ion and silicate dominate in dust on the leaf surface of *Sedum spurium* from a tram track.

Optical analysis of Sedum album from tram tracks and their immission induced dust layer

SEM/EDX

The immission induced dust layer on the leaves was examined by scanning electron microscope using energy dispersive X-ray (SEM/EDX; HITACHI S-520, DISS 5 and digital x-ray processor DXP-X10P) and Particle Sizing System. SEM/EDX-pictures of sedum proved the presence of particles belonging to health relevant fractions PM_{10} and $PM_{2.5}$. According to chemical and optical analyses much of it seems to be caused by abrasion (wheel, rail, break sand), since many Si - and Fe - particles were detected. This indicates that trams also emit particles belonging to the fraction PM_{10} and $PM_{2.5}$.

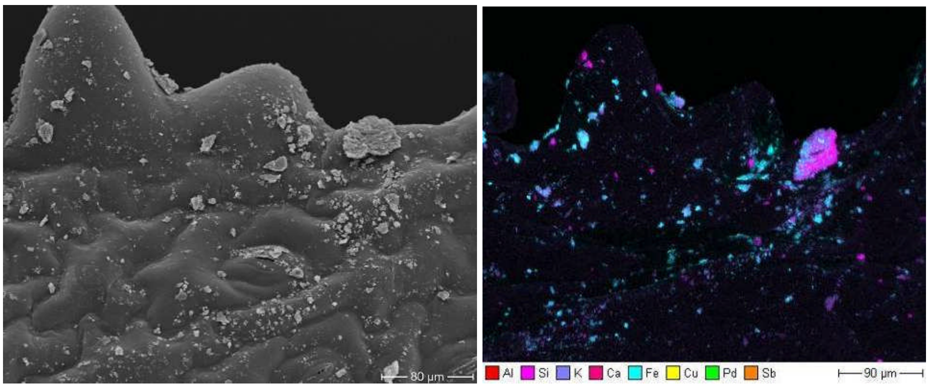


Figure 15

Dust layer on *Sedum spurium* leaf. LEFT: 80 µm; RIGHT: elemental analysis of dust layer, distribution of Fe and Si, 90 µm, (picture Schreiter)

During optical analysis aluminium, copper, chromium and manganese were detected in smaller amounts only, compared to ion and silicate. Many organic particles were evidenced. This elemental composition could be seen on most of the investigated leaves.

Figure 16
Comparison of uncleaned (left) and cleaned (right) *Sedum album* leaves, March 2009.

Especially during winter and spring almost 100% dust coverage of the plants in the tracks could be documented (see Figure 16). Precipitation had no noteworthy effect on the removal of the dust layer from the leaves. So accumulation of fine dust on the leave surface of sedum could be proven. According to the classification of leaf surfaces (THÖNNESSEN 2008) in accumulator and self-cleaner due to the properties of the leaf surface *S. album* und *S. spurium* can be classified as accumulator. In contrary to the leaves of *Sedum album* the petals show micro roughnesses, which cause a self-cleaning effect. Pictures from petals proved only little particle occurrence (see Figure 17).

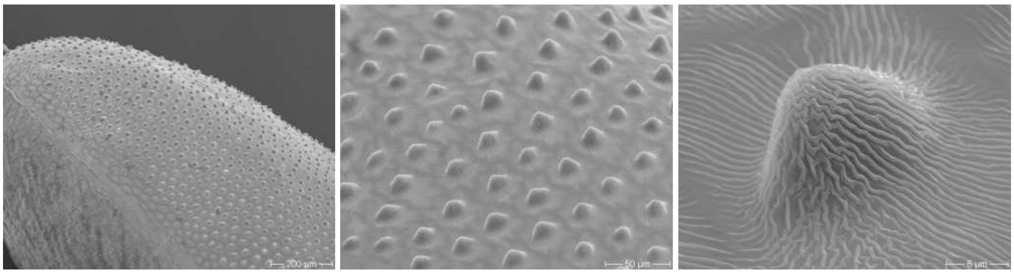


Figure 17
Petal of *Sedum album* showing micro roughness and dust only at the bottom side of the petal (left picture). Scale from left to right 200 µm, 50 µm and 6 µm, respectively. (picture Schreiter)

PSS

In order to investigate the immission induced dust layer from *Sedum album* leaves, shoots were shaken 30 s in distilled water by means of 'lab dancer', which did not remove the whole dust layer as controlled by SEM proved. The water was than analysed using an optical particle sizer (Nicomp 380/ZLS Submicron Particle Size/Zeta Potential Analyzer along with the AccuSizer 780). Due to the methodology used and the property of the measurement device, by water removable, none diluted, and non-magnetic particles could be measured only. Results show that 99% of the remaining particles were below 8 µm. The mean diameter of all particles detected was about 1,1 µm. The SEM pictures documented many particle agglomerations. Surely, they were at least partly dispersed by washing the dust layer off the leaves. This might be a reason for the sizes measured by PSS.

Wind tunnel investigations

In order to compare *Sedum album* and ballast regarding fine dust deposition and fine dust_resuspension those track cover types were investigated in a wind tunnel at Bergische Universität of Wuppertal, Germany.

Samples of pre-cultivated *Sedum album* and gravel (31,5/63) were placed in the middle of a wind tunnel at a field of a size of 85 cm x 40 cm. The dust input was located at one side of the tunnel. The ventilation was placed at the opposite side, which created an air stream that transported the fine dust. Calcium carbonate ($CaCO_3$, Ulmer Weiss XMF) was used as fine dust with particle sizes from 0,23 µm to 20 µm. The measuring devices were placed at 9 cm above ground of the tunnel. Measuring points were at 20, 50 and 80 cm of the tunnel width.

Figure 18

Samples in wind tunnel. LEFT: Gravel; RIGHT: *Sedum album*

Dust concentrations of PM_1, $PM_{2.5}$ and PM_{10} were measured at luv and lee of the samples. It was assumed that if much dust deposition would happen, the dust concentration from lee would be lower than the luv concentration. And on the contrary, in case of a significant dust binding, which equals reduced resuspension, the concentration at the lee side should not be much higher than at the luv side. For resuspension investigations, the air stream was run without dust. A high amount of dust was applied to the samples beforehand. Measuring devices were portable Grimm aerosol spectrometers. The air stream was directed downwards to the samples in an angle of 10°.

For deposition, significant acting factors were material, wind speed and dust fraction. Deposition of dust was significantly higher on the sedum surface than on the gravel surface. Lower wind speed of 1 m/s had a higher impact than a speed of 2 m/s. Biggest differences were found with particles of 2 - 10 µm in favour of Sedum.

For resuspension, significant acting factors are the material (ballast or sedum) and dust fractions. Resuspension of dust from the sedum surface back into the air is almost zero. It is lower than dust resuspension from gravel. Significant differences were found at 3 - 4 µm, 5 – 7,50 µm and 15 - 20 µm for the sedum. Smaller particles have a quite similar resuspension from gravel and sedum. Higher wind speed increases resuspension.

Differences in deposition and resuspension between both track cover types are assumed to be caused by surface properties (cuticula and leaf shape in contrast to ballast) and pore volume.

Waterbalance

Problem – Changed Urban Water Balance

Building type and density of most urban areas result in high surface sealing. This influences the water balance of cities with the outcome that water run-off is increased, water retention is reduced, more water is lead into canalisation, less evapotranspiration, reduced air humidity, and higher air temperature, which leads to the build-up of heat islands (KUTTLER 1990). Additionally ground water level drops due to reduced leaching.

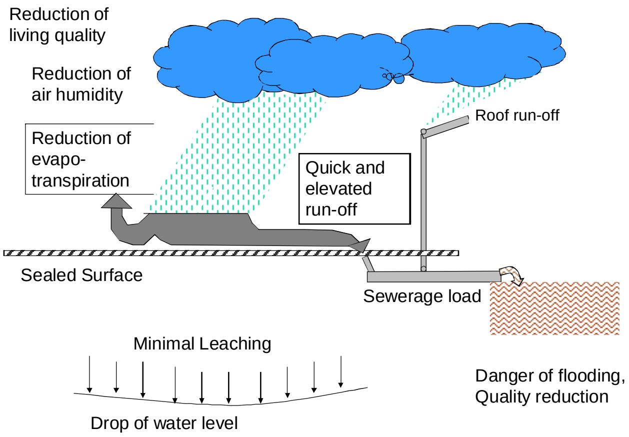


Figure 19

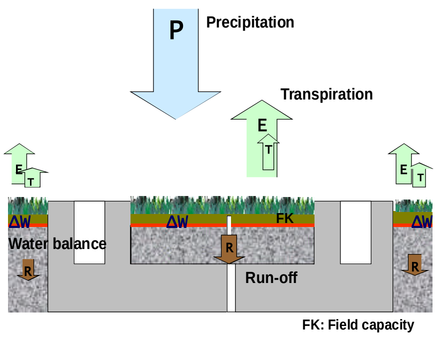
Negative influence of surface sealing onto urban water balance (ILS 1993, at TAPIA 2003)

Approach – Mitigation by Tram Track Greening

Technical vegetation systems unseal surfaces partly or totally, as widely investigated for roofs. Extensive vegetation systems in tram tracks retain on average 50% of precipitation, as Tapia and Model (2003) determined for a thin-layered vegetation mat with sedum - moss vegetation. Intensive vegetation systems in track beds with grass have not been investigated yet, but are assumed to retain 70% up to 100% depending on the system thickness, the intensity of the precipitation and the pre-saturation of the system.

As Figure 20 demonstrates, vegetation systems lead to delayed drainage, thus precipitation efflux peaks are reduced. This again relieves canalization. Due to that reason, in Berlin the rainwater fee for roofs is halved if they are green. Moreover, if using tram track vegetation at new construction sites sometimes compensation measures for the surface sealing cease to apply.

Evaporation of soil and transpiration of plants increase local air humidity. This way they decrease the local air temperature and support the mitigation of the heat island effect in urban areas.



P= Precipitation;
ET= Evaporation and transpiration;
R= Run-off;
ΔW= Water balance in the vegetation system [mm or l/m²];
FK= Field capacity

$$P = ET + R + \Delta W$$

Figure 20

Elements of water balance in a naturated tram track (TAPIA and MODEL 2003)

According to a survey by the IASP with German tram transport companies, 2009 Germany had about 4350 km of single track (slab track and ballasted track) (KAPPIS *et al.* 2010). Out of this total track length about 1142 km are potentially greenable. Approximately 375 km are momentarily greened. Thereof 326 km are grass tracks, with an area of 81,5 ha. Calculating with retention of at least 70% of precipitation, this area stores at least 453 460 m³ water. Germany has about 48 km sedum tracks, with an area of 12 ha. Calculating with retention of 50% of precipitation, more or less 47 400 m³ of water are stored. So using a yearly precipitation of 790 l/m² on average for the calculation 500 860 m³ is retained by the existing tram track greening in Germany. Should technical vegetation systems be applied onto the whole potentially greenable track length in Germany, more than 1,5 million m³ of rain water would have been saved in urban areas just by tram track naturation. Now, canalisation has to cope with this extra million m³ of water, and it is not available for urban microclimate.

Optic, Habitat

Tram tracks are part of the cityscape. Hence, the aesthetic appearance is an important issue. With the naturation of tram tracks, more green space is brought into cities. Green areas create a natural and calm atmosphere.

Figure 21
Sedum track, Berlin, Prenzlauer Allee, June 2009 (picture Schreiter)

Figure 22
Sedum track, Chemnitz, Goetheplatz

Some sedum varieties are evergreen. During winter bigger leaved varieties usually draw back a bit and moss develops. Furthermore, the vegetation is a habitat for innumerable insects and other invertebrates.

The installation of pre-cultivated sedum paver enables the naturation of tracks within hours or days. Figure 23 displays the sight of pre-cultivated sedum paver at different pre-cultivation stages.

Figure 23
Sedum paver after 3 months pre-cultivation (left), and after 1 year (right) at Niedersächsische Rasenkulturen NIRA, Germany

The sedum paver, which was installed in Brussels test site, showed red colour as stress symptom. Due to delay with the test site installation, the plants rooted into the Mypex underneath. So during harvest the roots needed to be cut. The plants were mowed prior to transportation to avoid damage. Additionally a heat wave occurred before harvest and went on some time after installation.

Figure 24
Brussels, Boulevard Leopold III, Sedum track before (left) and after naturation (right)

After installation, when rain events occurred fertilizer was applied onto the plants. Thus, the colour of the plants will soon have normalised and plants will have developed to a nice green cover.

LCC-Reduction

By means of life cycle cost (LCC)-calculations a prognosis of the expected results before the installation was done, based on the maintenance regime and costs structure of Brussels operator STIB. A comparison of a state-of-the-art-solution in comparison to the developed new solution for the specific building site, based on assumptions and the available data were done. The developed sedum version and a reference track of grass paver (greened on sight) as straight tracks with a length of 72 m each were compared in the LCC analysis. Figure 25 gives an idea of the LCC relations. These are no absolute values. Due to lack of data, they had to be partly estimated.

The sedum track system belongs to the extensive vegetation systems. It is characterized by its low maintenance need compared to grass tracks. It comprises fertilization once or twice a year.

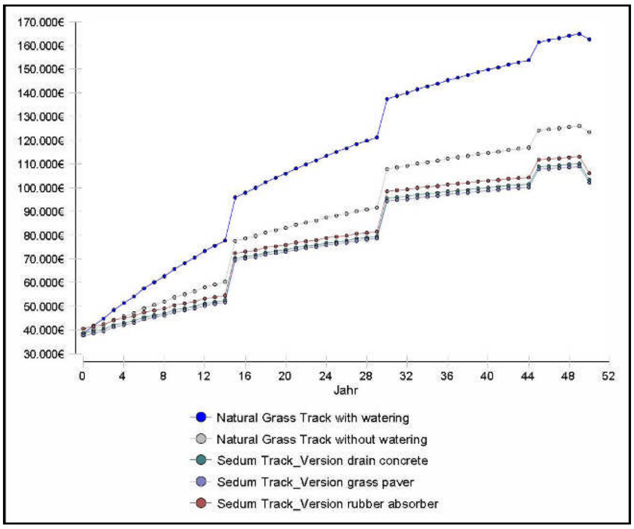


Figure 25
Cumulative LCC of the candidates over 50 years

There is no need for mowing or watering. Hence, the higher investment costs are soon amortised. Additionally the sedum paver can easily be moved out of the track and reinstalled again. The maintenance costs become less relevant at countries or areas where lower wages are paid.

Sometimes compensating measures have to be done or paid for sealing the surface with tracks. Greening the tracks is considered as unsealing of surfaces. So the compensating measures would cease to apply.

Conclusions

The developed track design was tested and designed to cover the demands made onto tram tracks. A well covered naturated sight was displayed straight after installation. Life cycle costs were reduced compared to the reference track due to the implementation of high quality long lasting materials and low maintenance needs of the vegetation system. The track is drivable due to plastic paver, which can take up to 20 t axle load. The vegetation system was designed to improve water balance in urban areas. Laboratory tests proved that sedum plants accumulate fine and coarse dust and thereby help to improve local air quality. The developed vegetation system aimed at mitigation of tram noise by using substrate with bigger grit size and by replacing the reverberant parts of the track by noise absorbing materials (drain concrete, porous rubber, and sedum paver). As laboratory tests showed a noise reduction of at least 2 dB (A) were achieved. Moreover, sedum plants can widely be used within the northern hemisphere, as long as the system is adapted to local conditions. Each location places certain demands to vegetation systems by its geographic position, its micro climatic situation and very local conditions, which need to be considered during planning.

Still, two kilometre of double track already make up one hectare. Thus regarding the urban and climatic trends, the naturation of building surfaces with its huge expanse poses several potentials which should be paid attention to. The developed track design using sedum paver and noise absorber offers a tool to use this potential.

Acknowledgements

The author wants to thank NIRA for support during the development of the sedum paver and preparation of the test site, Mr. Riffel (Heidelbergcement), Dr. Sorger (Wacker Chemie) and Mr. van de Ven (Interbeton) for supply of drain concrete, and our project partner CDM and STUVA for good cooperation.

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REMS: The successful development of a removable embedded rail system for Metro in Tunnel

Easy evacuation in case of emergency has become an important issue in metro tunnels. Embedded track systems with a flat surface well suit the recent focus on these requirements. The concern of metro operators about the easy replacement possibilities of worn down embedded rails has however been up till now an obstacle to the implementation of embedded tracks in tunnel.

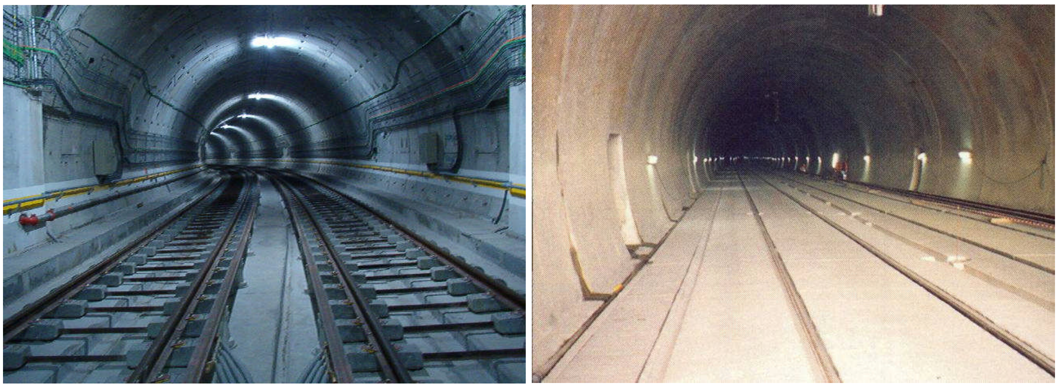


Figure 1

Evolution from open sleeper track to embedded track with flat surface for easy evacuation

The solution to this dilemma was the development of an all new concept: the removable embedded metro rail system (REMS) for use in tunnels. The main innovative aspect of this embedded metro track system is its capability to allow the easy and non-destructive rail replacement.

After extensive development and prototype testing, the system was validated in real tracks.

The development work started of with an in depth analysis of the state of the art analysis embedded rail systems which revealed that these systems had major shortcomings, in particular the use of non standard rail sections.

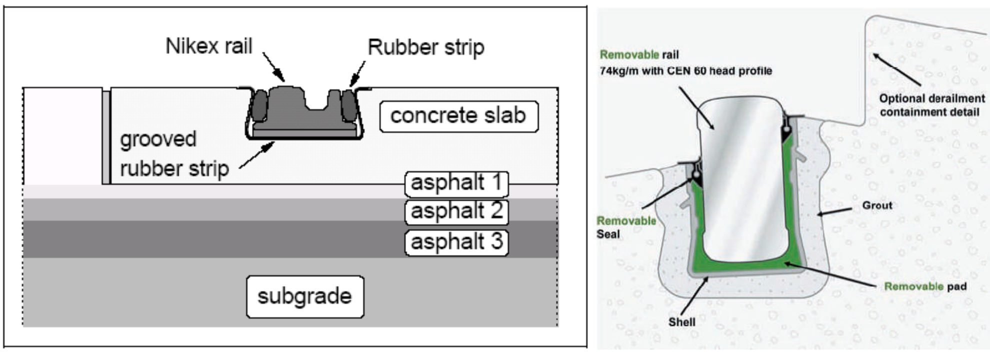


Figure 2

Two examples of existing removable embedded systems suffering amongst others from the disadvantage of a non-standard rail profile

This lead to the formulation of some alternative concepts based on standard rail, locking keys, rubber encapsulation elements.

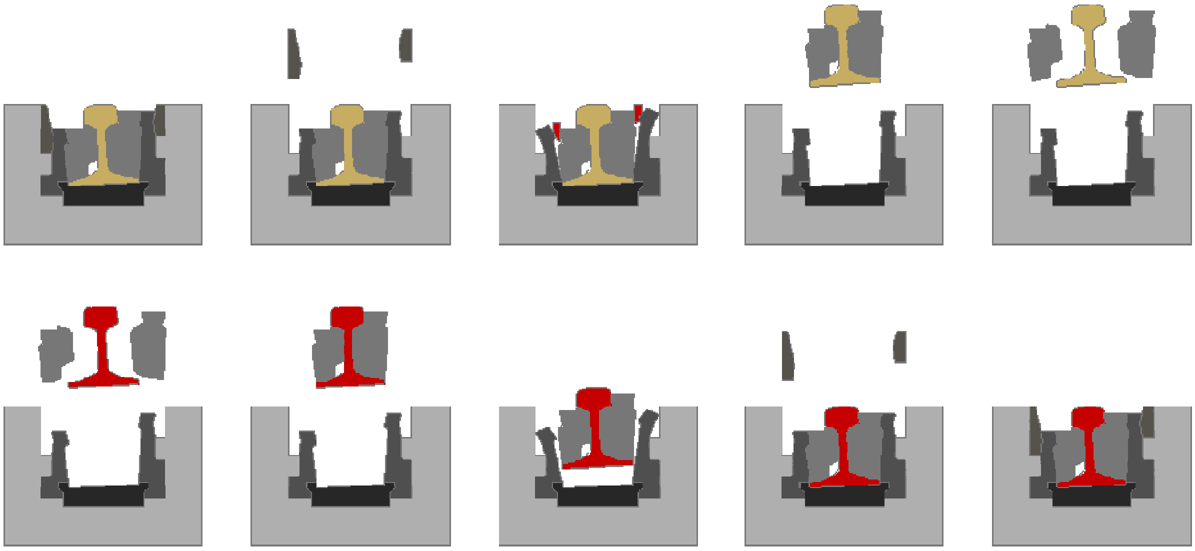


Figure 3

REMS rail replacement concept using keys

The installation method for the new track system was also defined. It uses top down construction by means of gauge frames that are adjusted to hold the rail properly aligned until the concrete is poured and hardened. No sleepers are used and the rail is continuously supported and encapsulated by the recycled rubber REMS components.

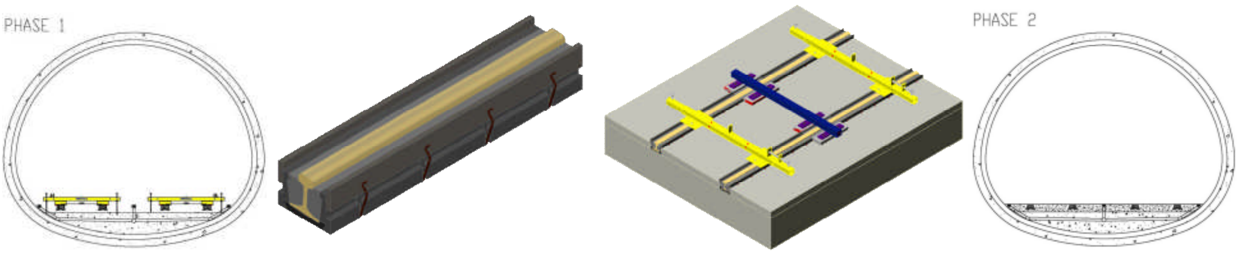


Figure 4

REMS top down installation concept using gauge frames

After thorough analysis and FEM simulations by the Politechnico di Milano, several prototypes were made for extensive lab testing. The testing included static and dynamic stiffness, fatigue, aging, longitudinal restraint, pull out restraint and of course practical rail removal.

Figure 5

FEM representation of REMS behaviour under load and example of test block and setup

The positive test results allowed going ahead with production development. Two production moulds were manufactured to allow industrial production of the various REMS components made from recycled rubber.

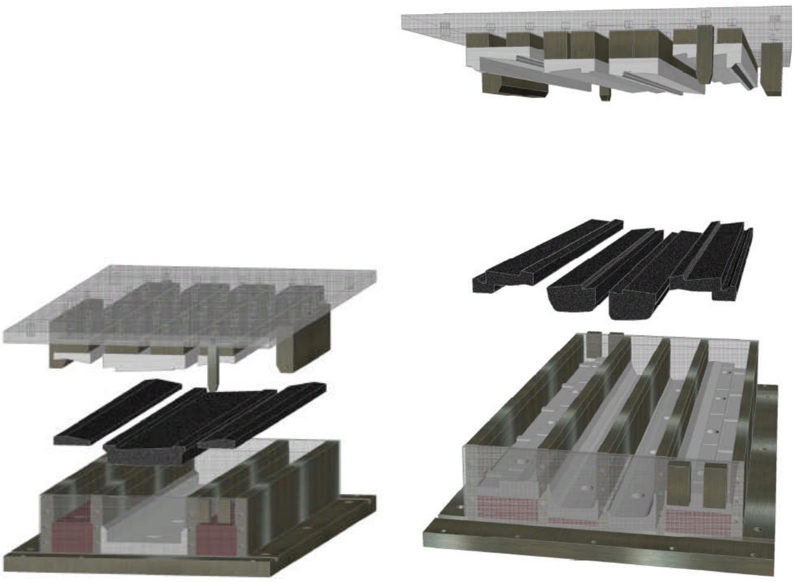


Figure 6
Production moulds for REMS components

The next step was the realisation of two validation tracks I the network of Metro the Madrid network, life cycle cost analysis and noise and vibration performance testing.

A first straight test stretch of about 50 meter in the open air was used to verify the feasibility of the installation and of the rail removal concept.

Figure 7
First REMS installation in Madrid

Rail displacement measurements during metro pass by were also performed to check the proper behaviour of the recycled rubber REMS rail encapsulation elements and to asses the track stability. The rail displacements proved to stay well within the required tolerances.

Figure 8
Embedded rail replacement test

After the initial feasibility test, a second validation track of about 50 meter in a curve inside a tunnel of the Metro de Madrid network was completed.

Figure 9
REMS installation in a tunnel of the Madrid metro network

The rail replacement test gave satisfaction and Ineco-Tifsa made several other tests such as rail stress, vertical deflection, gauge widening, and rail twist. D2S International made the noise and vibration tests.

Figure 10
Noise and vibration tests on reference track and REMS track during metro pass by

A final life cycle analysis comparing booted sleeper track in existing tunnel with REMS track in existing tunnel indicated a considerable LCC reduction of about 25% in favour of REMS.

The in service REMS tests track performance and experience have successfully validated this innovative track infrastructure development. Only the noise and vibrations performance was not better than that of the ballasted track. Nevertheless, Metro de Madrid approved the application of REMS for wider use in their network.

The REMS project has thus become a successful example of innovation in accordance with the Urban Track objective to functionally develop track systems while meeting the goals of 25 % in life cycle costs.

CDM-ELASTIPLUS: DEVELOPMENT OF A VERY RESILIENT FASTENER AS AN ALTERNATIVE TO FLOATING SLAB SYSTEMS AND AS A SOLUTION TO EXCESSIVE RAIL CORRUGATION

In the past, track infrastructure manufacturers have developed several direct rail fixation systems. These systems are however not able to match the performances of floating slab tracks in terms of noise and vibration.

Floating Slab Tracks

A floating slab track is a vibration isolation system of 3rd level, based on the principle of a concrete slab supported on an elastic medium (mats, strips or pads). The noise and vibration performance of such a system can be approximated by a mass spring system, where the concrete slab, the rail fixation, the rail and the rolling stock represent the mass and the resilient mat acts as the spring. For such system, the resonance frequency is given by:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}\ (\mathrm{Hz})$$

with k = dynamic stiffness of the resilient mat
m = involved mass above the mat

Since a floating slab is a 3rd level isolation system, the suspended mass "m" is very high, resulting in a system with a low resonance frequency and a very good isolation performance in the critical frequency range.

However, the installation of these systems is not always as easy as the installation of direct fixations. Besides, the floating slabs require a certain depth of the track infrastructure that it is not always possible because of the tunnel diameter limitations.

Because of all these reasons, a new resilient fixation system called CDM-Elastiplus has been developed within the URBANTRACK project as an alternative to a floating slab.

Working principle of the Elastiplus device

A low resonance frequency can be obtained either by increasing the mass of the system or by using a resilient material with a lower dynamic stiffness. A direct rail fixation is a 2nd level vibration isolation system, which means that there is no possibility to act on the suspended mass (these are: base plate, rail and rolling stock). So, a low resonance frequency can only be achieved by decreasing the dynamic stiffness of the resilient material, and thus also decreasing the static stiffness, which will increase rail deflection.

However, rail deflection is normally limited to a few millimetres to ensure track stability. This normally puts a limit on lowering the dynamic system of the resilient material. Therefore, the performance of classical direct rail fixations is limited by the required track stability. The CDM-Elastiplus fixation device overcomes this limitation by imposing a pre-compression of the resilient material.

The following figure shows the working principle of the CDM-Elastiplus fixation. The pre-compression imposed by the compression spring is such that the additional deflection at maximum load is below the requirements for track stability.

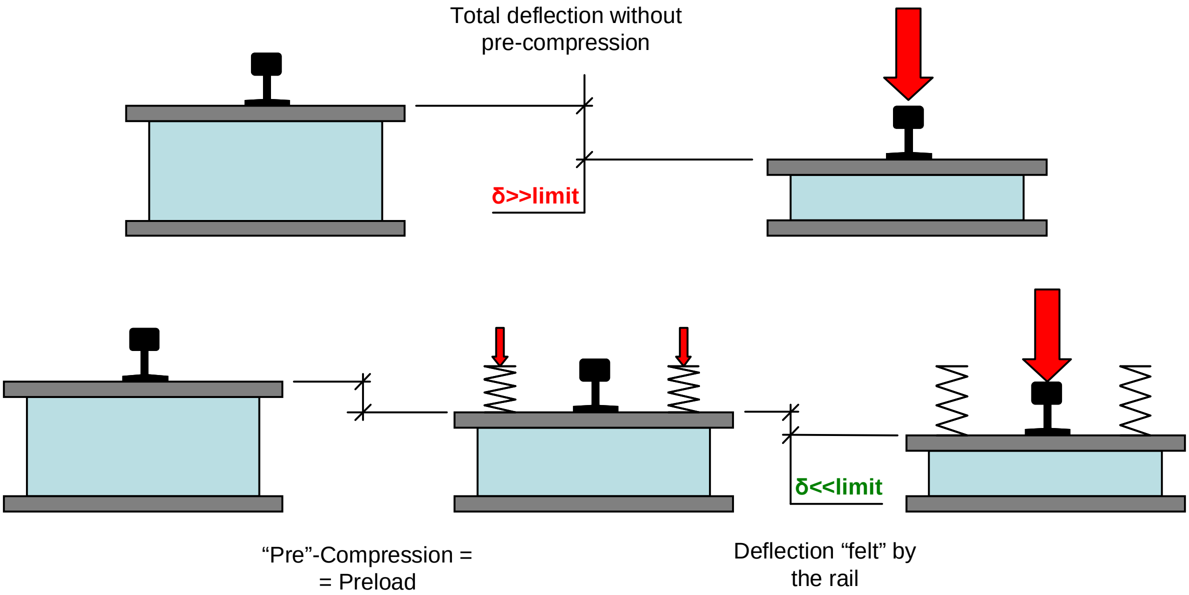


Figure 1 CDM-Elastiplus working principle

The above scheme represents the interaction between the elastomer and the pre-compression springs and the final deflection of the rail when the fixation is loaded. In order to use the low dynamic stiffness of the resilient mat and to prevent the transmission of structure borne noise from the base plate through the springs into the tunnel invert, it is very important that the compression springs release as quickly as possible during wheel passage.

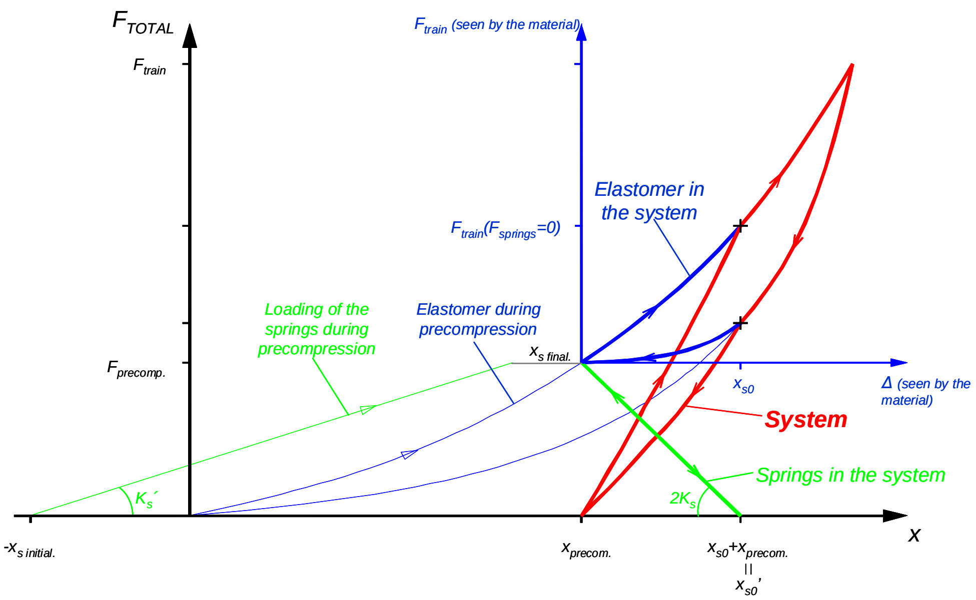


Figure 2 CDM-Elastiplus working diagram

Rail corrugation reduction

One of the conclusions of European Research Project CORRUGATION stated that the "combination of high resiliency and minimal deflection of the rail results in a low track stiffness that minimizes the stresses in the rail and eliminates corrugation growth". This leads to less rail grinding.

Thus, the CDM-Elastiplus fixation is not only good for vibration isolation, but is also an excellent solution to combat rail corrugation.

Realization of the device

The CDM-Elastiplus system was designed according to the above working concept. The result is an in-factory fixation pre-compressed that is adaptable to the requirements of a particular project: rail type, clips, stiffness and other parameter can be tuned.

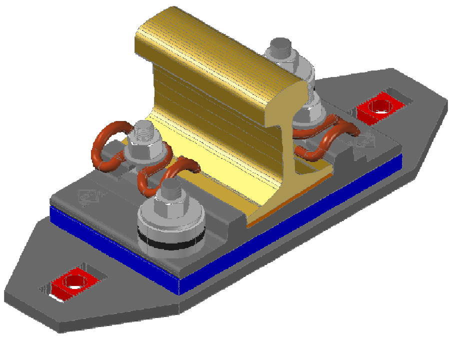


Figure 3

CDM-Elastiplus device

Lab tests on the fixation showed promising results for static and dynamic behaviour for long term use. These results where successfully demonstrated in two homologation tests at both "Instituto de Ciencias de la Construcción Eduardo Torroja" in Spain and at "Universite Catholique de Louvain" in Belgium.

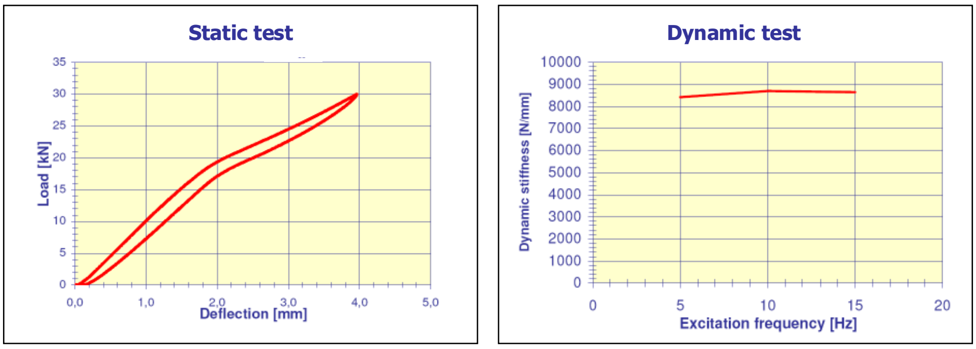


Figure 4

CDM-Elastiplus results for TMB parameters

LCC calculations

A detailed Life Cycle Cost calculation was carried out by comparing the CDM-Elastiplus system with two other systems: a floating slab track and a classic direct fixation fastener installation. For both cases, the new developed resilient fixation showed a reduction in the LCC of around 25%, mainly due to the reduced maintenance requirements of this system.

Alternative to Floating Track Slab with High Attenuation Sleeper

Specific objectives of study

The specific objectives targeted by the development of an alternative to floating slab track were to reach the following technical characteristics:

- Solution for metro environment (18t axle load, 100 kph).
- Equivalent vibration performance to Floating Slab Track (selected reference: Taipei OBLEX currently installed by ALSTOM).
- Ability to meet all railway constraints.
- Safety (derailment) including track level evacuation:
  - Comfort;
  - Maintenance.
- Construction method:
  - For standard equipment and methods;
  - Production rate as conventional track slab.
- Lower costs compared to conventional Floating Slab Track:
  - For capital portion (design + procure + build);
  - For maintenance portion.

Chosen concept

The approach to define the concept started with a review of existing systems worldwide.

A previous generation consisting of bi-block sleepers was installed for CTRL Section2 by ALSTOM with:

- Relatively low weight;
- Tie bar overstressed with very soft pads;
- Track gauge variations with very soft pads.

Following this first analysis, the choice fell on a concept based on a monobloc resilient sleeper.

The high attenuation properties are due to:

- A high sleeper mass (350 – 400 kg);
- Very soft resilient inserts (8KN/mm/fastener).

This concept is adapted to track-laying gantries.

It is moreover maintenance friendly compared with conventional Floating Slab Track.

The figures below give an overview of the chosen concept based on mono-block resilient sleeper.

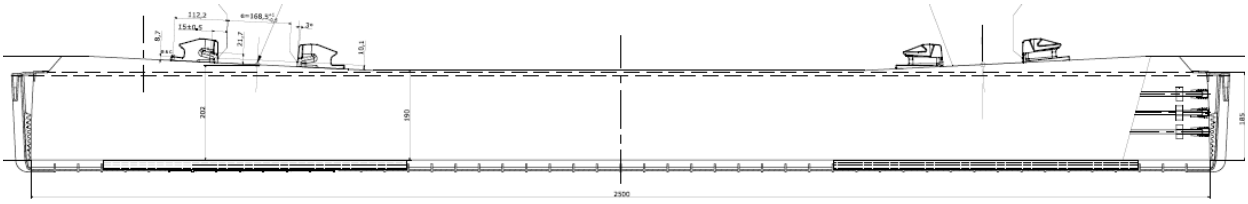


Figure 1

Transversal view of monobloc sleeper

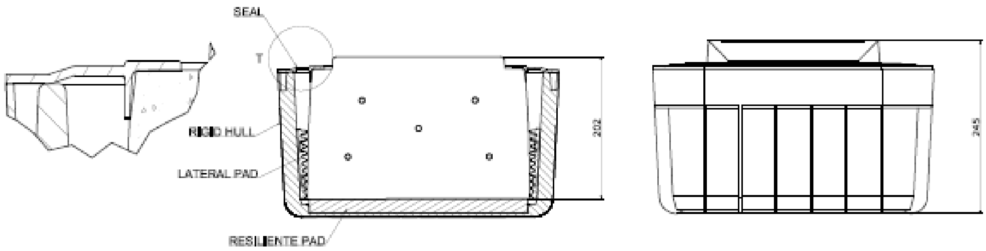


Figure 2

Side view of monobloc sleeper

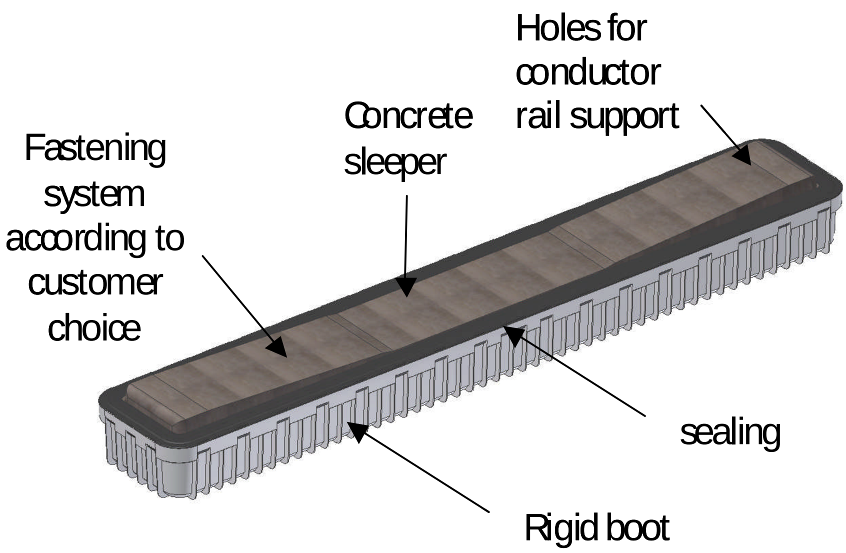


Figure 3

3D-view of the monobloc sleeper

Detailed Design and Laboratory Test

Insertion gain target

The performance of a vibration mitigation system is measured by the insertion gain obtained by comparing the studied solution with a reference track, which has no vibration mitigation properties.

The insertion gain of the High Attenuation Sleeper was defined in reference to several existing vibration mitigation systems.

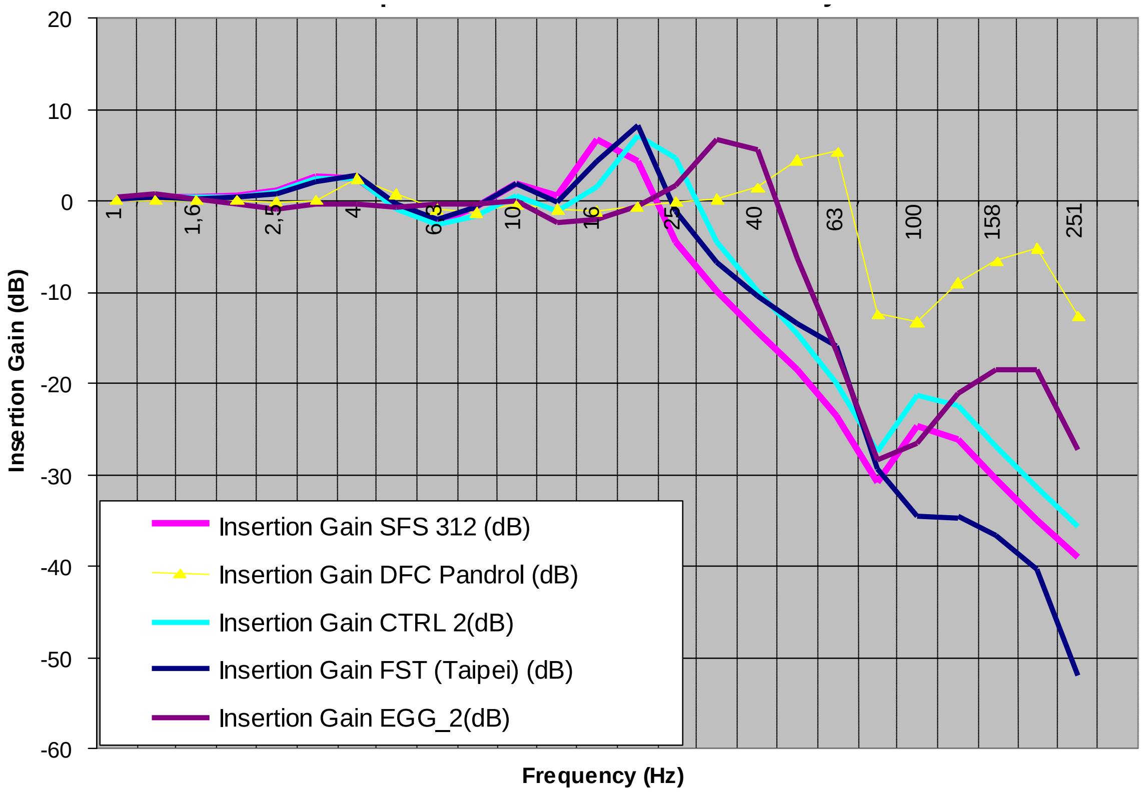


Figure 4 Comparison with different vibration mitigation systems

Typical tunnel layout

The typical tunnel is shown on the figures below. The design is fully compliant with most rail fasteners.

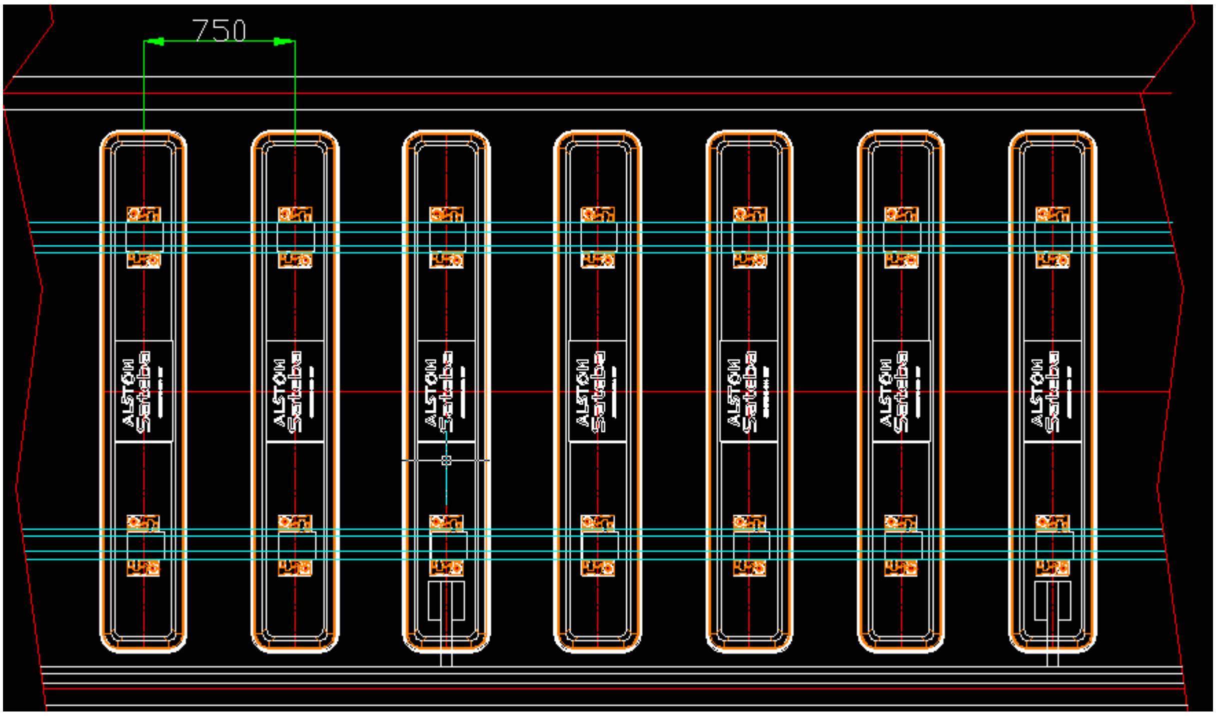


Figure 5 Longitudinal track layout

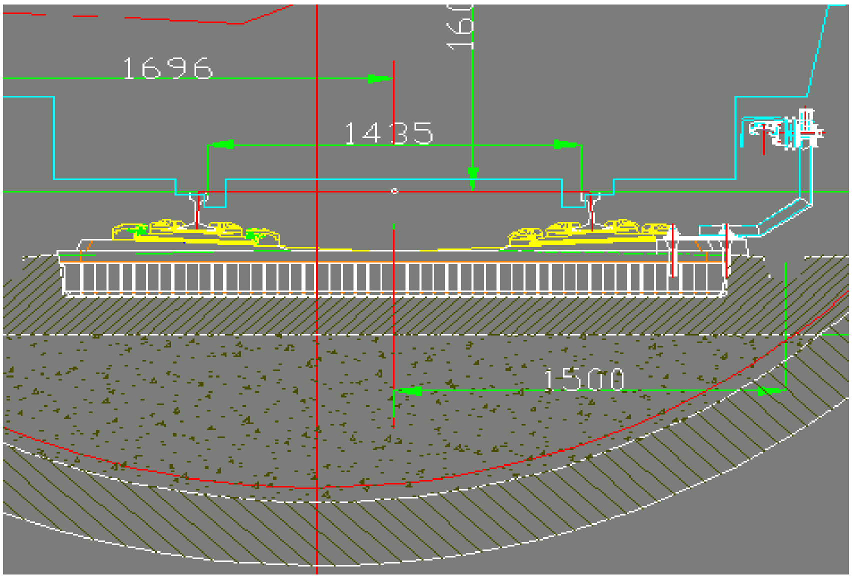


Figure 6
Typical cross-section

Typical case of impact on tunnel diameter

Installing a High Attenuation Sleeper as an Alternative to Floating Track Slab has a significant impact on civil works.

The estimated gain compared with Taipei OBLEX is 20 cm on tunnel diameter as shown on figure below.

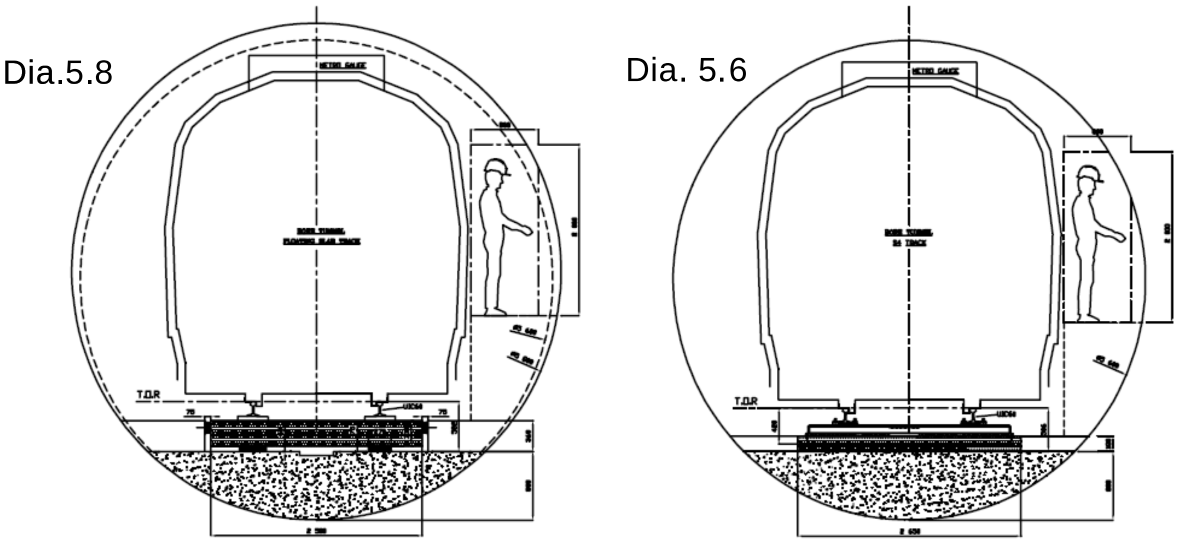


Figure 7
Impact on tunnel diameter - Conventional FST (Taipei OBLEX) vs. High Attenuation Sleeper

Dynamic testing regime

Mechanical tests were carried out to validate the fatigue behaviour.

Fatigue test with inclined loads was done according to the following phases:

– 1 MCycles @ low frequency (3 Hz) applied load between 10 kN and 75 kN, centred, inclined at 38°;

- 0,5 MCycles @ moderate frequency (5 Hz) applied load between 30/40 kN and 75 kN centred, inclined at 38°;
- 2 MCycles @ low frequency (3 Hz) applied load between 10 kN and 75 kN, inclined at 10° and 38°;
- 1 MCycles @ moderate frequency (5 Hz) applied load between 30/40 kN and 75 kN, inclined at 10° and 38°.

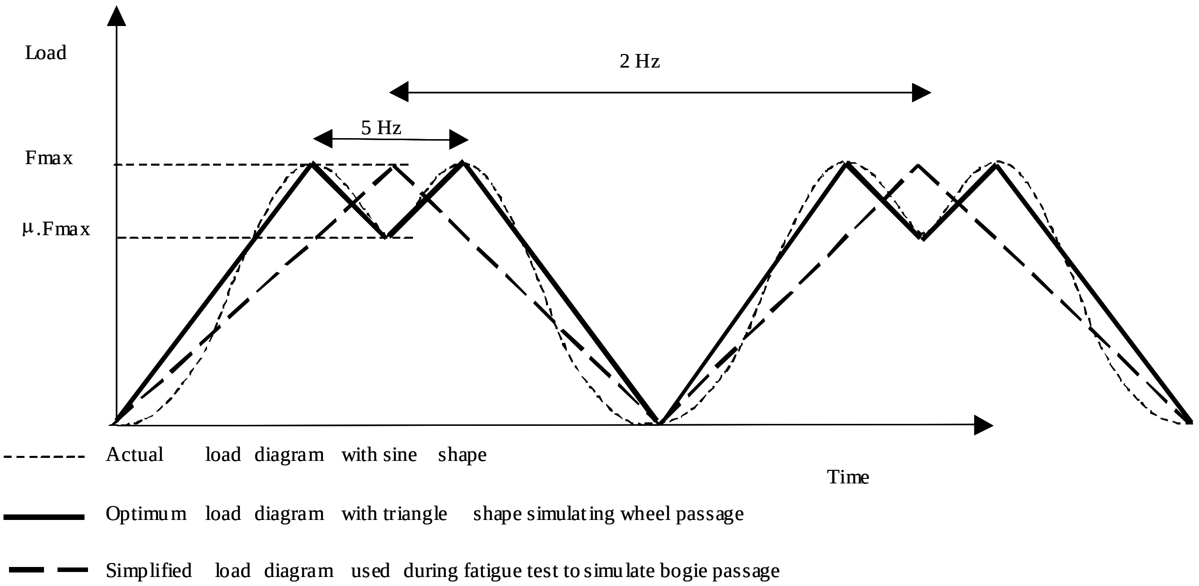


Figure 8

A total of 4,5 millions load cycles were achieved with success: no pad wearing & no vertical stiffness loss after (EN13230 specifies 2 million cycles).

Lab testing arrangements

The two pictures below show the testing arrangements for vibration mitigation and mechanical tests.

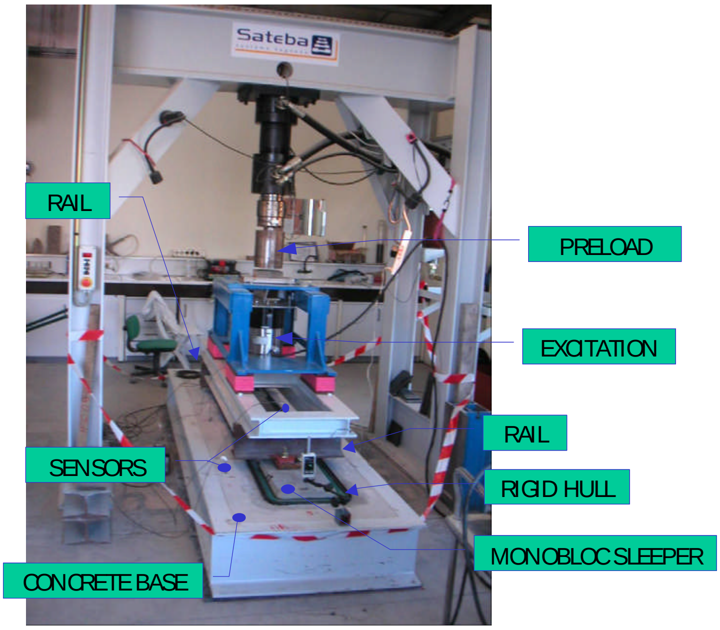


Figure 9
Vibration mitigation test arrangement

Figure 10
Mechanical test arrangement

Dynamic test results

The dynamic stiffness obtained from the lab test are summarised on the graph below.

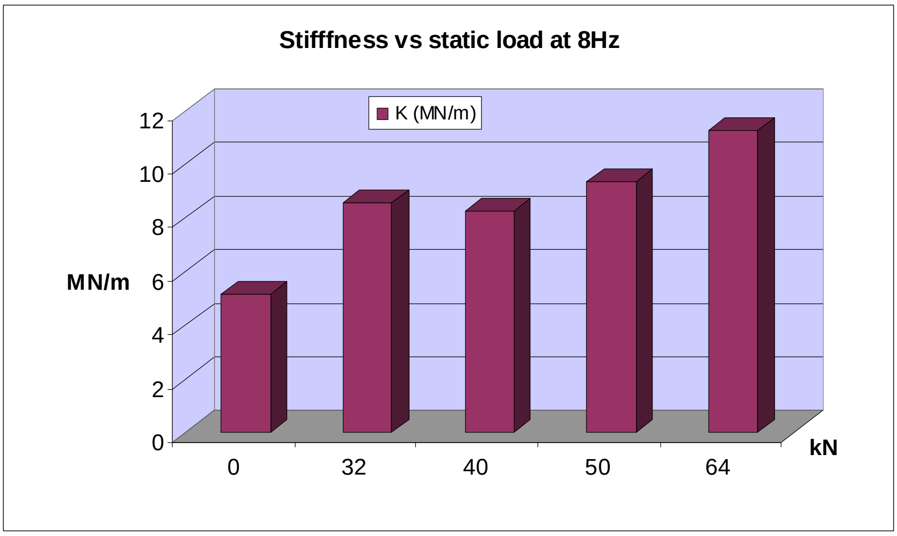


Figure 11
Dynamic stiffness under various preloads

The lab tests results have been promising for the future validation on site.

Validation

Site description

The test section is located in a curve with a 190 m radius and a 160 mm cant.

The track to be replaced by the Alternative to Floating Slab Trackform consisted of:

- A ballasted track;
- Fishplated U50 rail;
- Good ground conditions: EV2 above 80 MPa.

General Layout

The general layout consists of 50 m of High Attenuation Track with 2 x 6,5 m of transition slab with ballasted track.

The sleeper spacing is 700 mm.

The rail is welded in the high attenuation zone and fishplated joints are installed at each end of test site allowing for expansion movement.

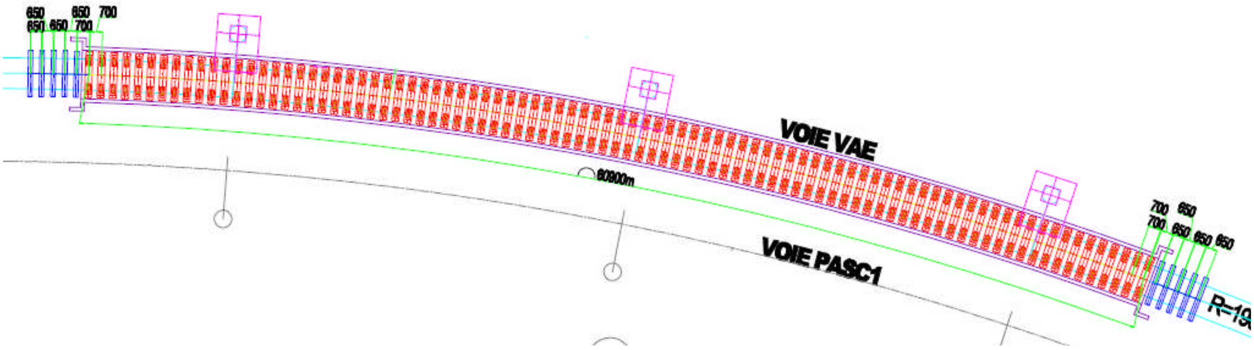


Figure 12

General layout - overview

Detailed design concept

Installing a concrete track section at-grade required the design of a foundation slab, which would reproduce the bearing capacity of a tunnel invert.

The track section consists of a reinforced U-shaped foundation filled-in with a second stage concrete where the High Attenuation Sleepers are embedded (see figure below). This track « slab » concrete is un-reinforced with frequent joints to avoid shrinkage cracking.

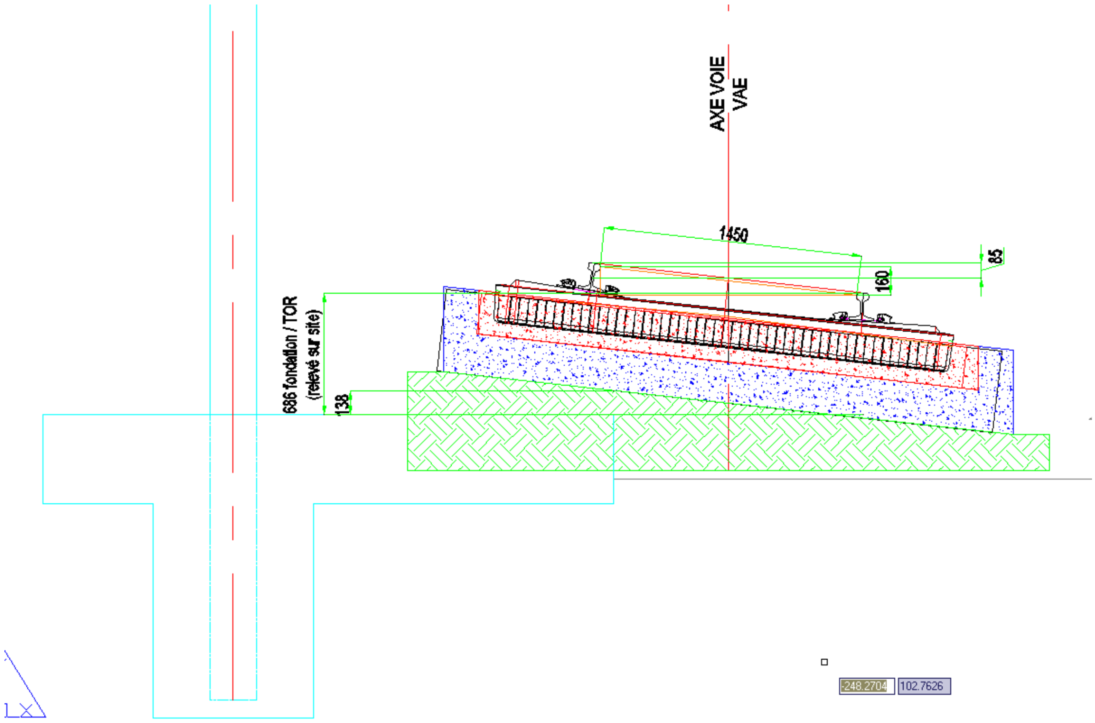


Figure 13

Track section

The detailed design was developed based on the following assumptions (valid after vibration testing):

- Axle load: 25 tons;
- Total cumulated load: 280MGT;
- Undersleeper resilient inserts to replace by stiffer inserts (30 MN/m);
- Structural design based on EUROCODE 2:
    - Load Model 71;
    - Crack 0,2 mm.

Construction phase

The construction started early May and finished early June. One month was kept for drying concrete.

The pictures below give an overview of the construction phase.

Figure 14
Construction after concreting of foundation

Figure 15
Construction before track slab concreting

Testing phase and performance measures

Early July, after the concrete has dried, the testing of the High Attenuation Sleeper plain track and the transition zone was carried out under the circulation of an ALSTOM metro vehicle and consisted of:

- Train induced vibration levels:
  - On track slab concrete, and;
  - Outside U shaped foundation.
- Rail and sleeper deflection of both rails.
- Rail and sleeper lateral displacements.

At least 6 pass-bys at 60 km/h and 30 km/h were recorded for each section, except for the ballast section where only pass-bys at 60 km/h were recorded.

Accelerometers were placed on the rail, sleeper, slab and soil as indicated in the figures below.

Sleeper vibration is measured in 3 dimensions.

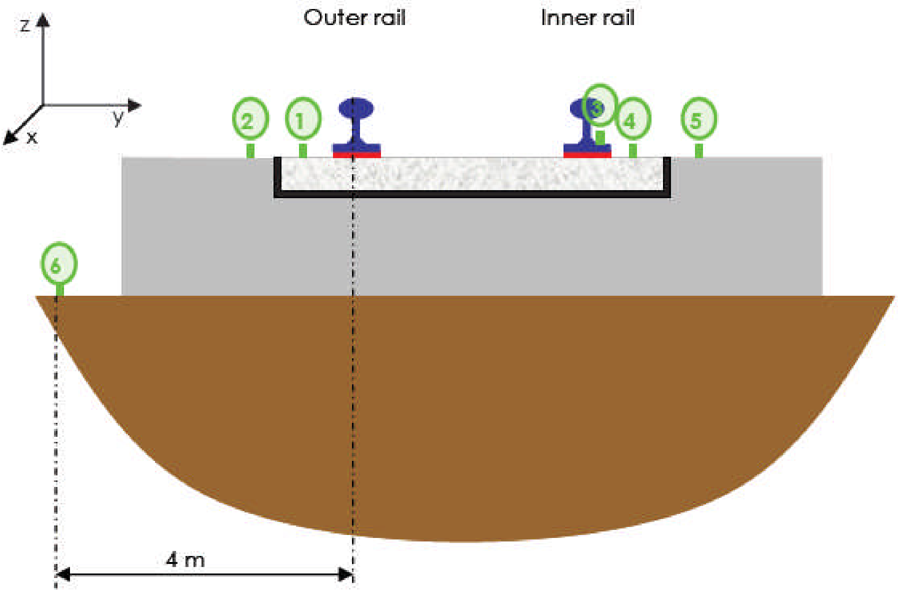


Figure 16
Sensor positions for dynamic measurement on concrete track

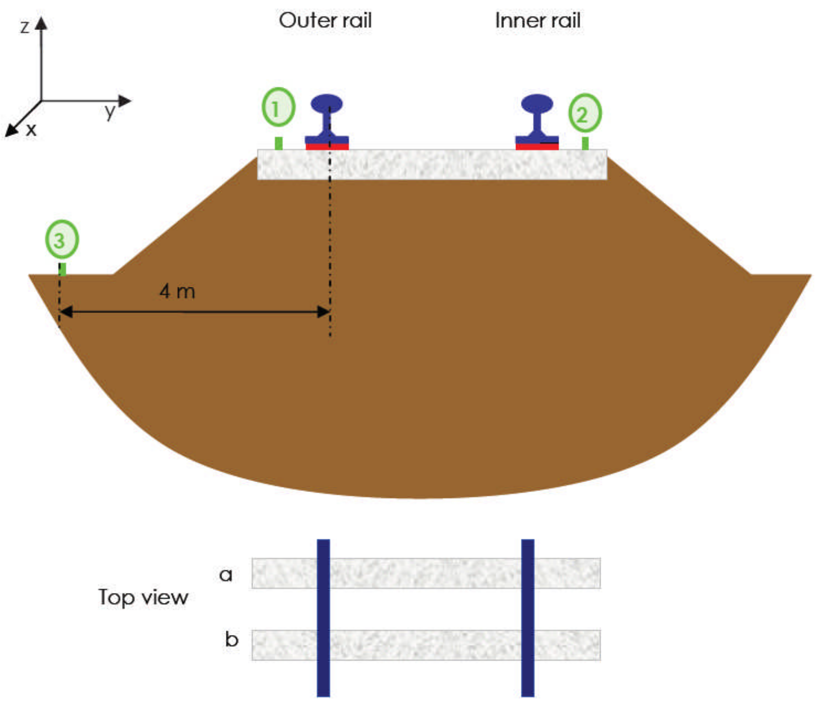


Figure 17
Sensor positions for dynamic measurement on ballasted track

Vertical and transversal displacements are measured on the rail and on the sleeper for both the inner side and the outer side with respect to the slab.

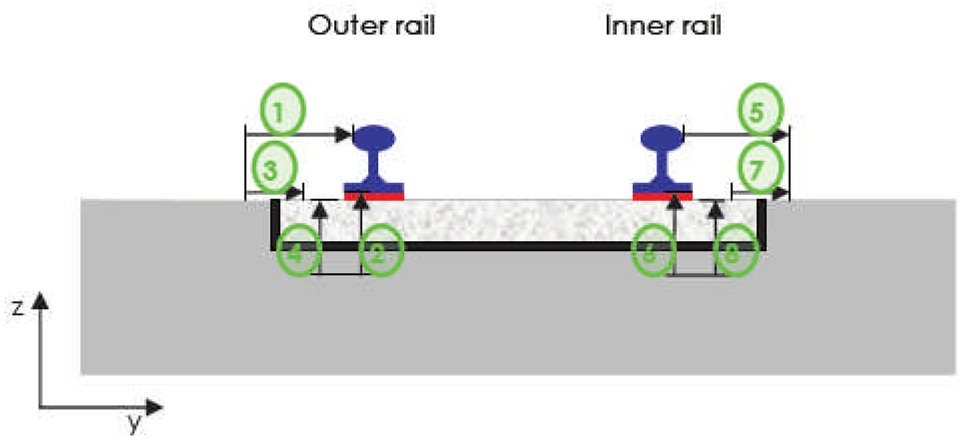


Figure 18
Displacement sensors position on concrete track

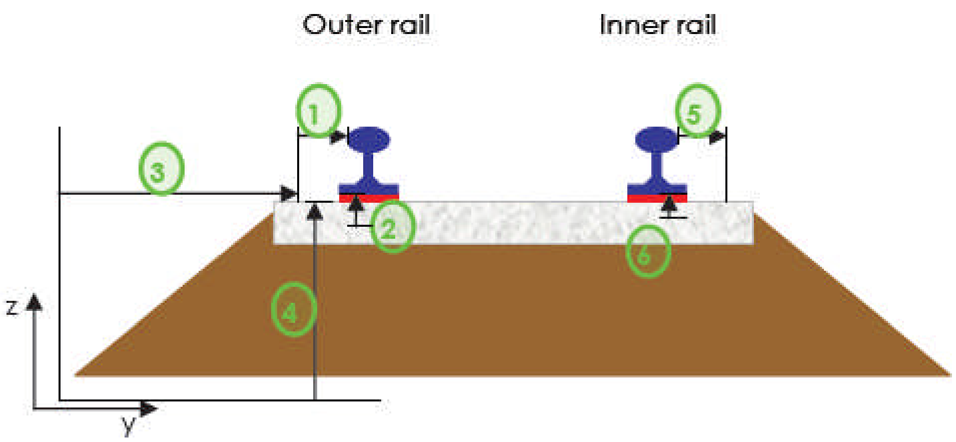


Figure 19
Displacement sensors position on ballasted track

In addition, strain measurements were achieved in order to fully encompass the mechanical behaviour of highly resilient track system.

Captors were placed on rail foot over a 5-sleeper spacing per measurement site i.e. plain track and transition zone.

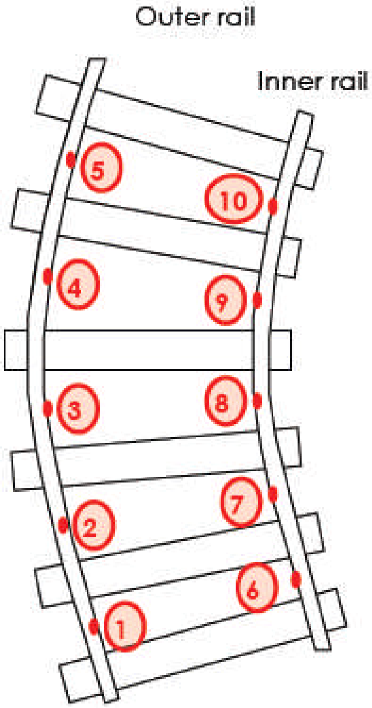


Figure 20

Strain gauge location

Results

Depending on speed (30 km/h or 60 km/h), the effect of centrifugal force can be seen on vertical negative displacements (downwards) at the inner side and at the outer side of the curve.

Same observation can be made for the horizontal negative displacements (outwards).

The following vertical negative sleeper displacement at 60 km/h could be measured for:

- The ballasted track section: -4,61 mm*,
- The transition track: -0,64 mm and
- The concrete plain track: -1,99 mm (1st zone) and -1,85 mm (2nd zone).

The high displacements that could be observed on the ballast sleepers indicate that the sleeper is not probably very well fixed.

The tensile stresses measured are greater than the compression stresses in the rail at all places.

The vibration mitigation performance can be summarised in the curve below:

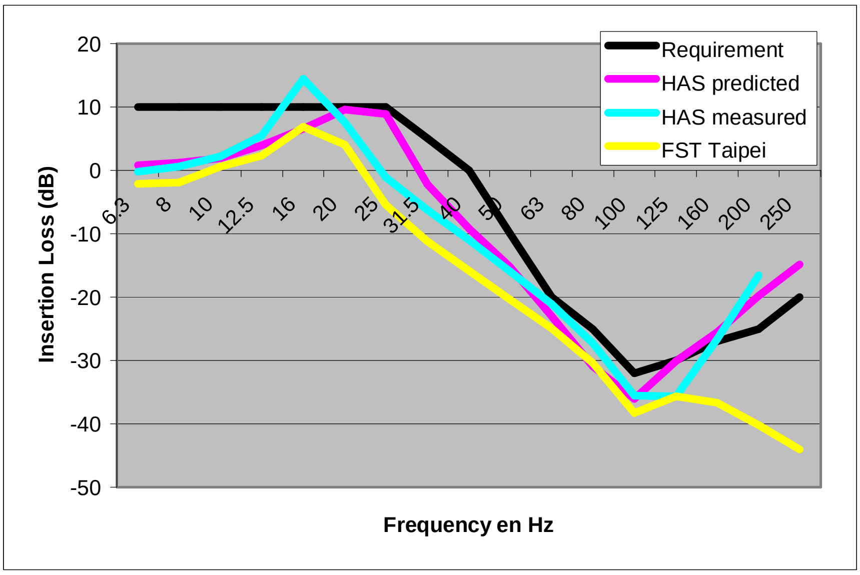


Figure 21

Insertion loss graph (ref. PACT)

Predicted and measured curves are very close. The insertion gain curve of the High Attenuation Sleepered track is close to the Taipei Floating Slab Track one.

This result shows the technical viability of installing a High Attenuation Sleepered track as an alternative to floating slab track.

Conclusions

The cut-off frequency of the insertion loss is similar to that of existing floating slab track and the vibration attenuation is very satisfactory.

It is technically viable to install a High Attenuation Sleepered track as an alternative to floating slab track.

An LCC analysis of the High Attenuation Sleeper as an alternative to the conventional floating slab track was carried out in parallel and shows a gain of 43%.

The technical viability is reinforced by an economical viability.

Savings are obtained through design, procure and build costs and also through maintenance costs, which are much lower. Moreover, there is a potential to reduce tunnelling costs.

So the high performance alternative to floating track slab is ideal for underground metro applications, it could absorb railway loads applied to sensitive bridges, and eventually could be implemented in high-speed tunnel.

APT-FST - Alternatives for floating slab at grade

Introduction

The idea of working with a load redistribution structure came after analysing the contents of a specific article "In service tests of the effectiveness of vibration control measures on the BART rail transit system" by Hugh Saurenman and James Philips, Journal of Sound and Vibration 293 (2006) 888-900.

In this article, they show the measured vibrations and line source transfer mobilities at different sites: standard ballasted track and floating slab. From the presented measurements, it is suggested that a big part of the vibration isolation performance of the floating slab must be coming from the presence of the thick concrete slab under the floating slab.

Also NS (Dutch railways) did experiments (1996) with a continuous concrete slab under the ballast tracks with the objective of reducing vibration levels in the neighbourhood. This has been reported in an article 'Proefvak trillingsarm spoor nabij Oosthuizen' by H.G. Stuit, Hollland Railconsult, Innovatieforum 231096. With a continuous concrete slab under the tracks, a reduction of the vibration levels has been measured by only in the very low frequencies.

No vibration reduction has been measured above 5 Hz, which can be explained by the fact that the concrete slab itself exhibits low frequency resonance frequencies, which can increase the transmitted vibrations.

The observations described above are used to introduced a load redistribution structure (LRS) which can be a concrete slab, under the classical track (e.g. ballasted track) or integrated in the classical track (in case of a direct fixation track). In order to perform well in terms of vibration isolation in the frequency range up to 70 Hz, such a LRS must exhibit a first bending resonance frequency, which is above the first wheel/rail bending resonance frequency (typically around 63 Hz or lower). This idea has been patented and tentative designs for the LRS have been made and dimensioned. The effect of the LRS in terms of vibration isolation has been calculated. The LRS does not interfere in the design of the track and its components: it is a low cost solution without any adverse effects on noise emission.

Description of the principle

Load redistribution plates will reduce vibration levels at the source under condition that these plates are stiff enough. In other words, they must have a first resonance frequency that is significantly higher than dominant wheel/rail resonance frequency. Since the dominant wheel/rail resonance frequency of the reference STIB/MIVB tram tracks is situated around 40 Hz, in order to function properly, the load repartitioning plates should have a first resonance frequency above 60 Hz.

Advantages

The main advantage of the load repartitioning plates is that this solution can be easily integrated in the track foundation. This results in a low initial cost, easy and rapid installation, smaller construction depths.

Speed of implementation: the time frame to install the load redistribution plates will be considerably less compared to a reference system consisting of a floating slab for tramway track.

Reduction of the vibration levels: vibration levels as measured along the test section should show a notable reduction of the vibration levels afterwards, compared to a reference section in the same street (track in other bound).

Reduced life cycle cost: the principle to install load redistribution plates with well chosen dynamic properties is a very innovative aspect. The initial low cost and no further maintenance for these plates contributes to a low life cycle cost compared to reference systems with similar vibration mitigating performance (floating slabs).

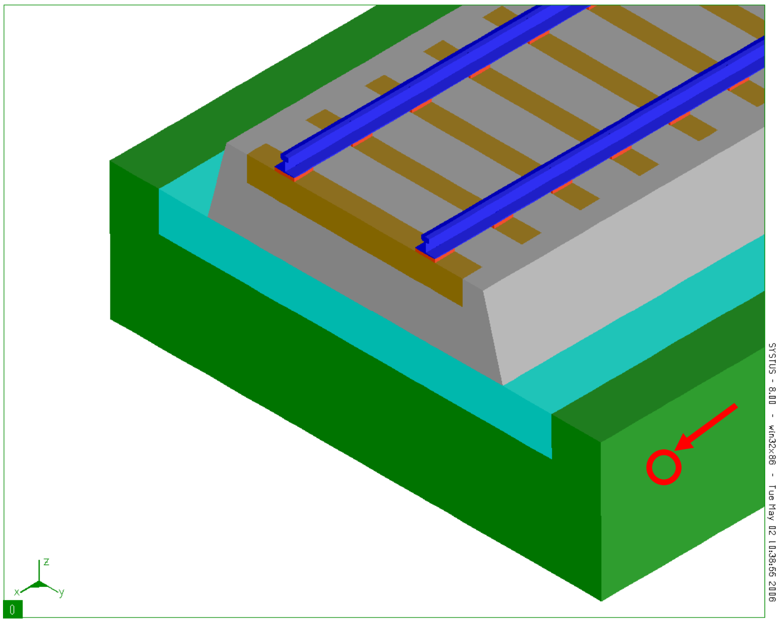


Figure 1
Schematic view of the integration of the load distribution plates in the track structure

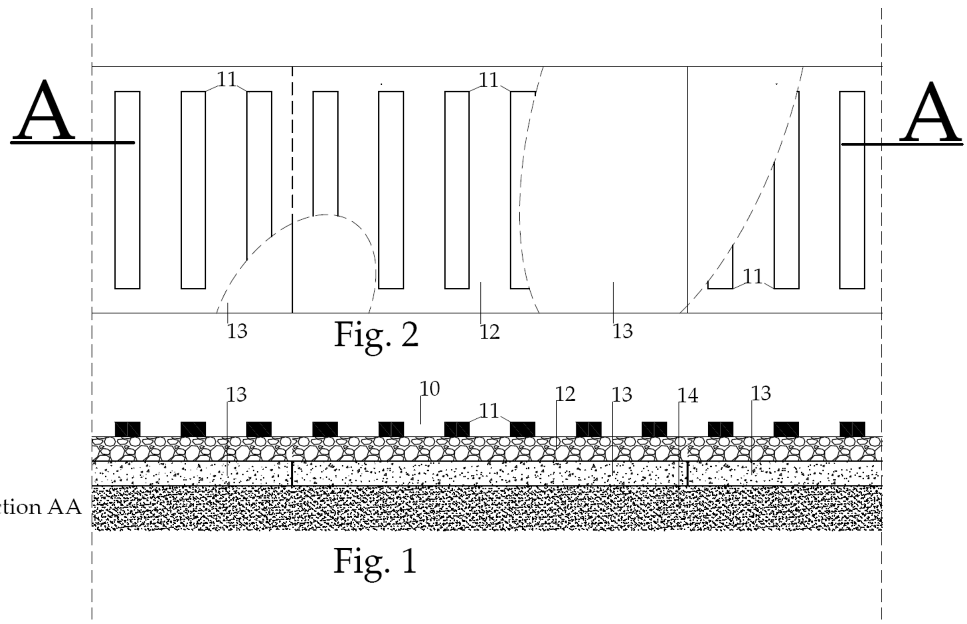


Figure 2
Schematic view of the placement of the slabs under ballasted track

Description of the installation

Test section

STIB provided a test section on a new tramway extension in "Rue du Chateau d'Or".

The test section met the following requirements:

- A new extension to validate the ease of installation;
- A limited height restriction in the underground to install the load repartitioning plates;
- Offer the possibility to make a straightforward comparison with a reference system.

The test section has a length of 100 m, which implies the installation of 200 load distribution plates.

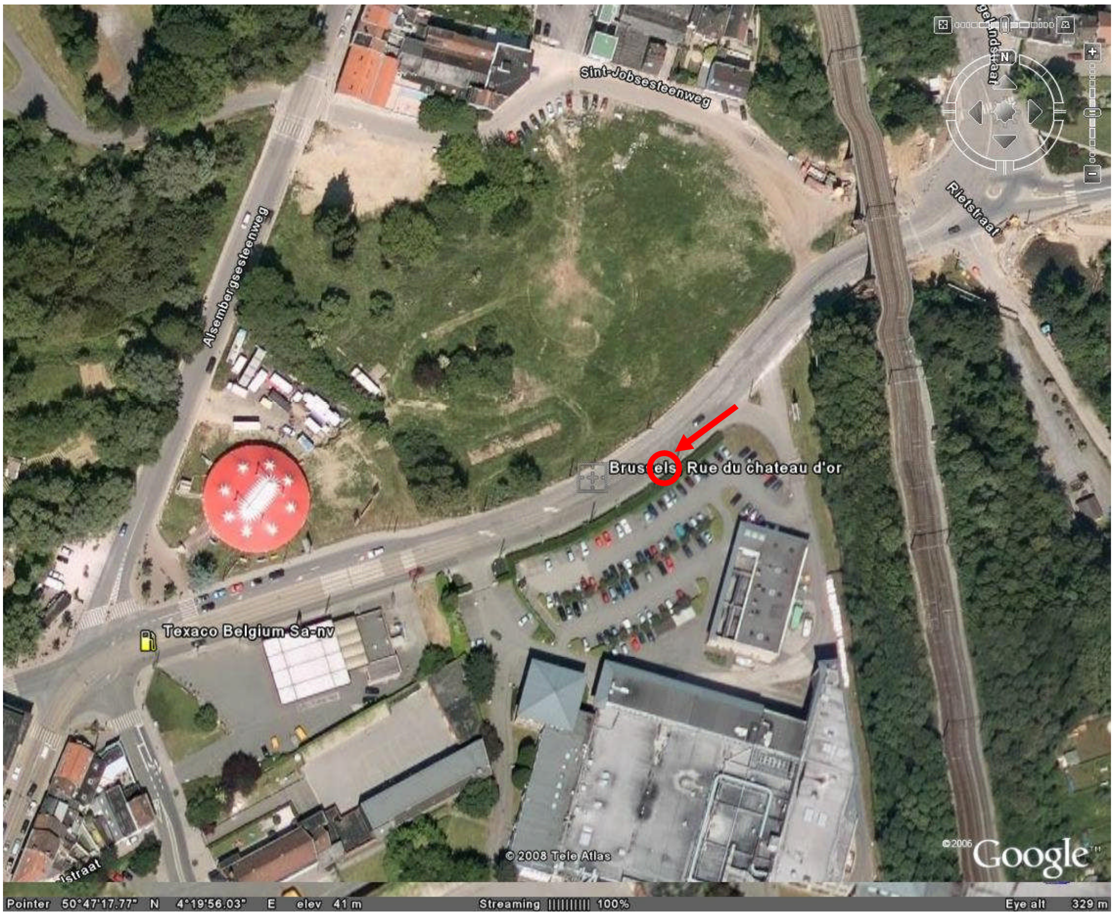


Figure 3
Location of „Rue du Chateau d'Or"in Brussels

Final design adapted to local site conditions

Final design calculations

Based on the available height (max 0,15 m in the cross section), the minimum height for rebars (10 mm) and the width 2,2 m, which corresponds to the largest width of the sleepers, the first resonance frequency was calculated to be situated above 60 Hz (ballasted track) in order to be effective (WP1.2.3, SP1).

A similar calculation as the one below, resulted in following dimensions of the load redistribution plates: 2,3 m x 0,5 m x 0,12 m.

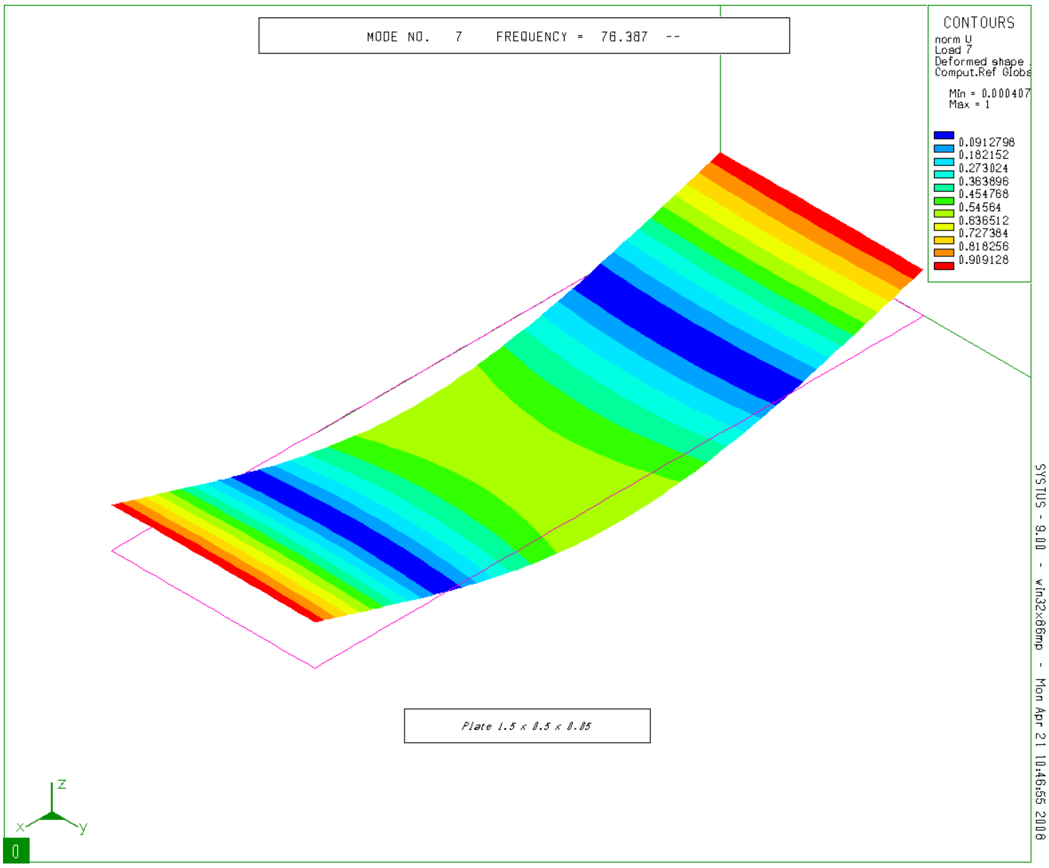


Figure 4 Example of the calculation of the resonance frequency of the load redistribution plate

Final design drawings

Based on the calculations mentioned above, following final design drawing was produced.

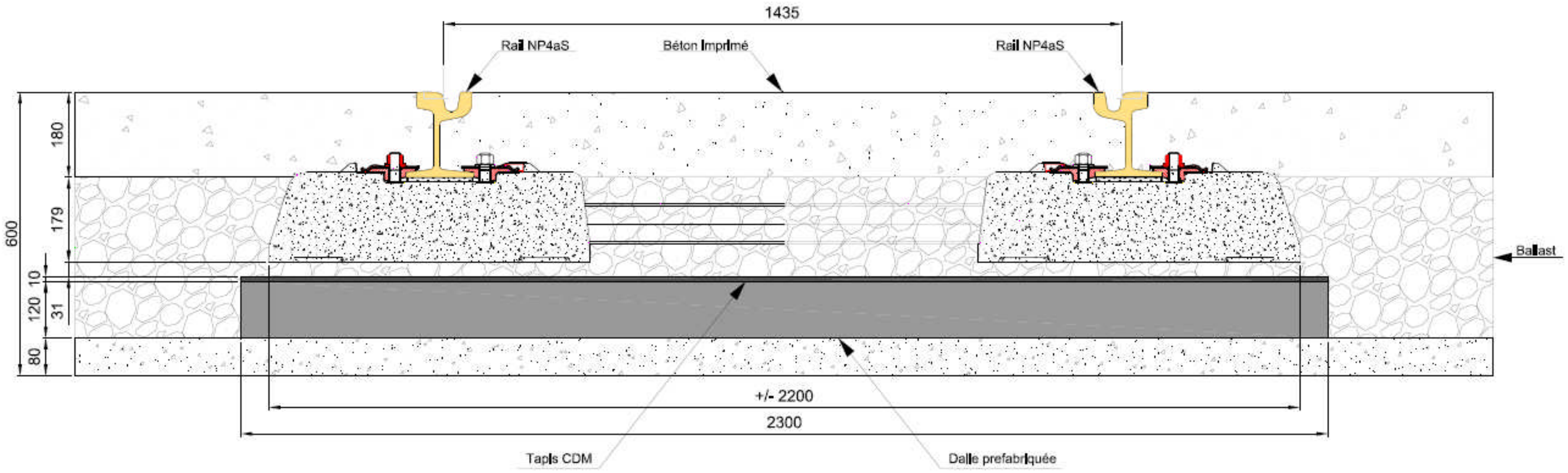

1435
Rail NP4aS
Béton Imprimé
Rail NP4aS
180
179
600
10
120
31
80
Ballast
+/- 2200
2300
Tapis CDM
Dalle prefabriquée

Figure 5

The final design drawing indicates the concrete covering, the standard sleepers, the ballast, a stiff elastomer to protect the ballast and the load redistribution plate.

Installation

The positioning of the thin foundation slabs is shown in the picture below. The plates will be installed on only one track. A reference track (bibloc-sleepers on ballast) will be installed on the other track, in order to perform an appropriate validation of the new system after installation. A stiff rubber mat on top of the slabs will protect the ballast.

Figure 6

After the positioning of the thin foundation slabs, ballast is put onto the slabs (approximately 12 cm) and on the ground of the other track. The next phases in the construction are identical for the two tracks: bibloc sleepers, fastenings, rails and pavement.

Figure 7

Results and Conclusions

The results of the comparison are shown below. All values and curves are average values. It can be seen that trams running on the track with the load redistribution plates produce less vibration than on the reference track.

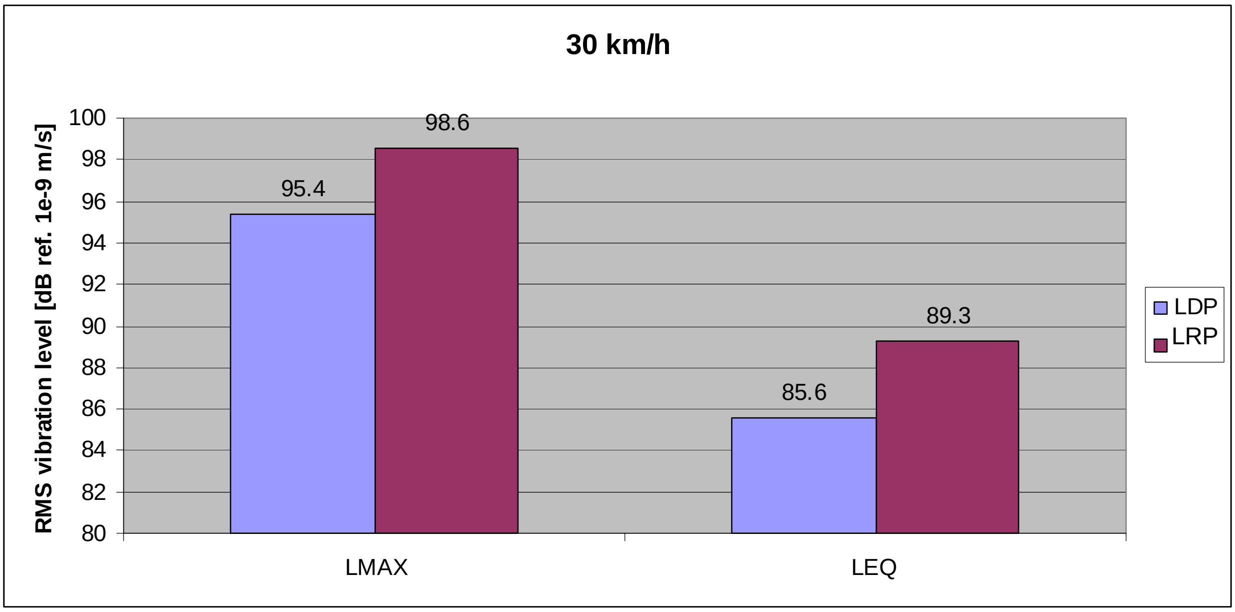


Figure 8

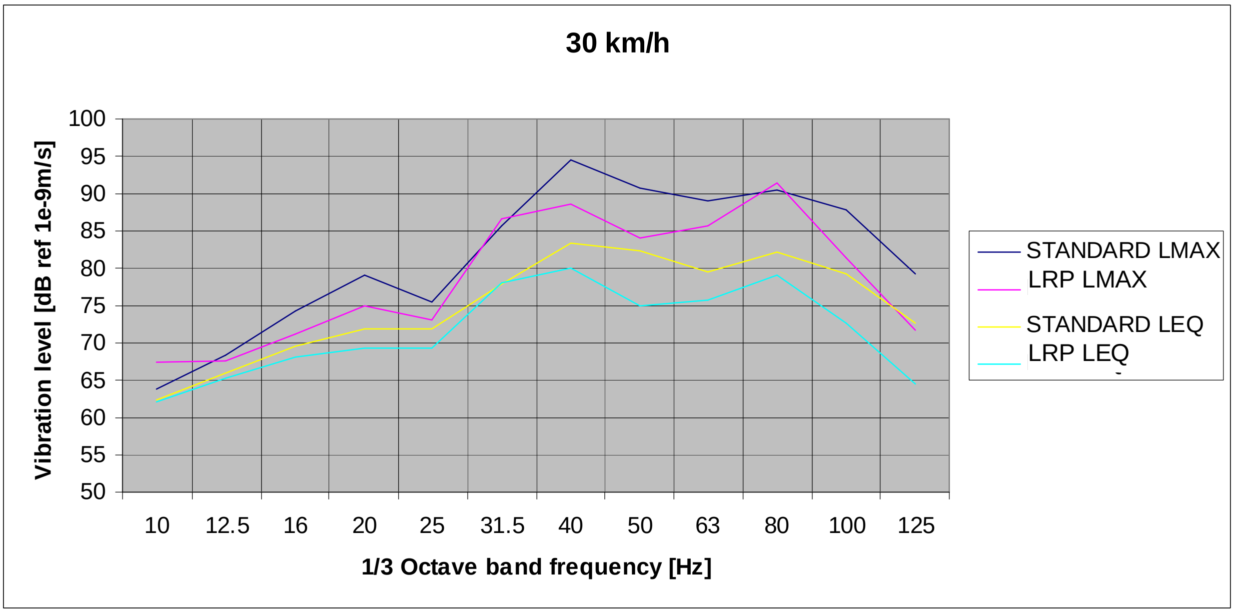


Figure 9

The performance of the new concept clearly depends on the reference. For tracks with a higher wheel/rail resonance frequency, the objective will be higher (5 to 10 dB should be achievable) since more mitigation can be obtained. For tracks with a lower wheel/rail resonance frequency (coming from a more resilient track and hence better load-distributing track) a performance up to 5 dB should be achievable.

RAPID IMPLEMENTATION

BREMEN (D) - TRAM TRACK REPLACEMENT TECHNIQUES

Introduction

Over the last century, the techniques for the renewal of urban tram tracks at Bremer Straßenbahn AG (BSAG) underwent an important evolution. Depending on the operational relevance of the tram track, renewals were done in small sections during the nightly service breaks, under the "rolling wheel", or by establishing single track sections with temporary switches during the entire construction period.

Since the year 2000, a construction method has been implemented by Bremer Straßenbahn AG (BSAG) that allows replacing between 200 m and 250 m during a full track closure of 57 h (one action-weekend between Friday 7 a.m. till Monday 4.00 p.m.). During this time the complete track including groundwork, concrete slabs and rails are installed and are ready for operations following Monday at 4.00 a.m. This construction method enables the replacement of an entire track section during a weekend.

Description of the test site

The site to be selected must meet the following demands:

- A track section in need of renewal,
- A complete 4 week closure for individualised motorised traffic had to be possible for that site,
- A minor percentage of heavy-load traffic,
- A possibility of tram detour.

An evaluation of all possible locations led to the selection of the site "Bei den Drei Pfählen".

Overall situation

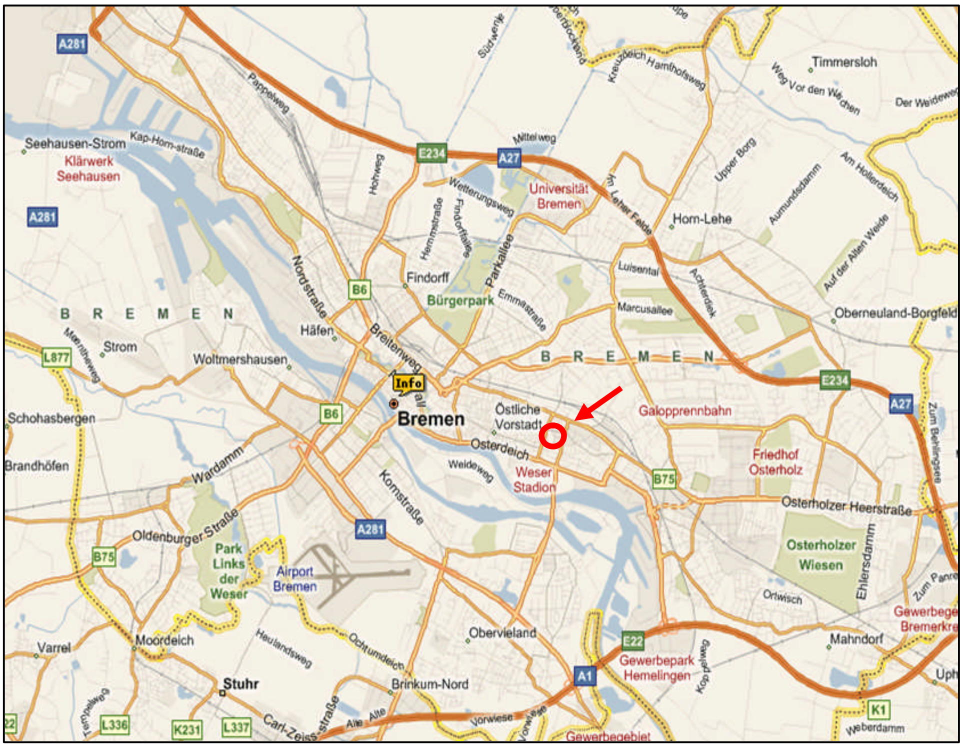


Figure 1
Location of „Bei den Drei Pfählen" in the city

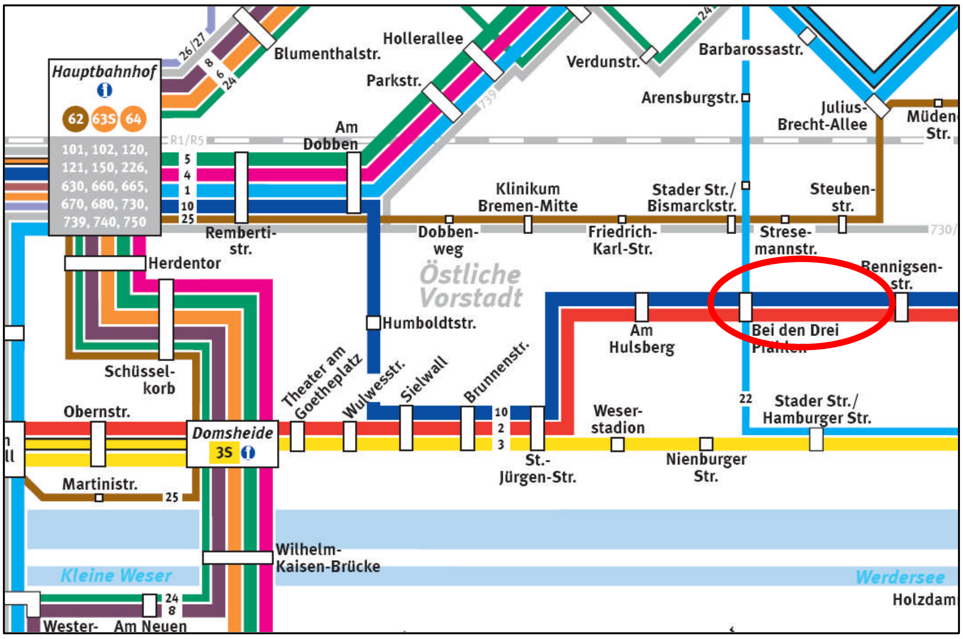


Figure 2
Tram Network at „Bei den Drei Pfählen" in Bremen

Local situation

Figure 3
Location with access to building site

Actual condition at test site

A typical double track tramway section on the middle of the street, shared with cars and trucks will be renewed. The track structure consists of grooved rails in a cobblestone paved road surface. The entire structure is in urgent need of renewal. The joint grouting is damaged and has already been repaired in a rough-and-ready way by botching up with asphalt.

The following pictures show the tracks' condition.

Figure 4
Track condition "Bei den drei Pfählen" in Bremen

Planning and coordination

The figure shows a typical cross section of the construction site.

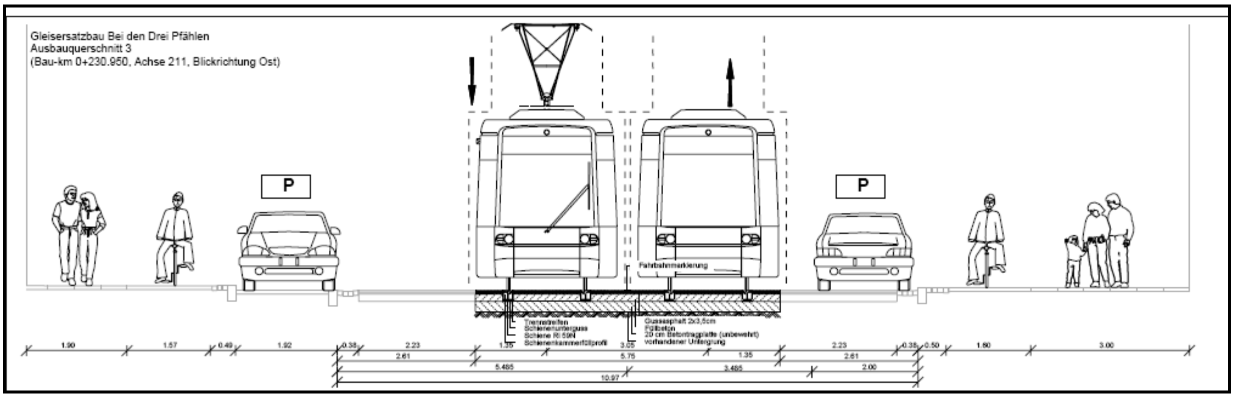


Figure 5

The figure below shows the track layout. The dark grey section on the upper plan is the intersection “Stader Straße” where anthracite coloured concrete surface was built in.

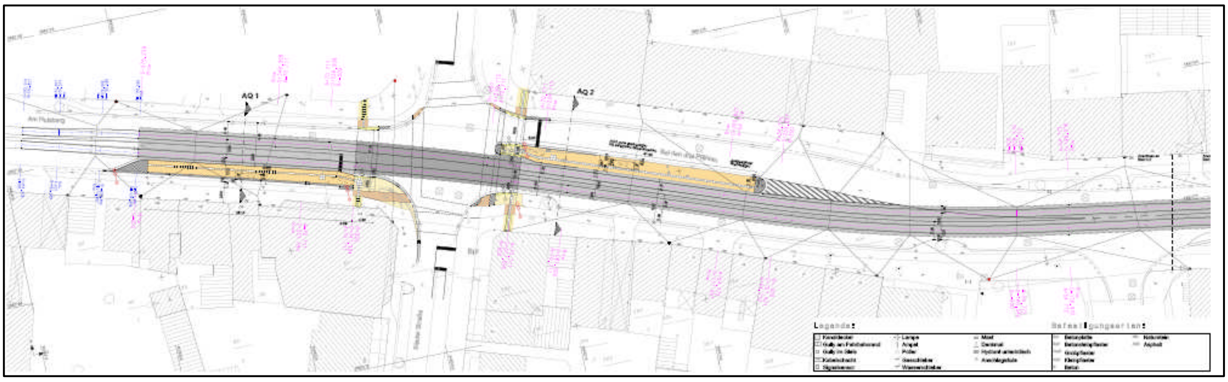


Figure 6

Location with access to building site

Hereafter a short list introduces key figures of the building activities taken from the call for bids.

Masses	Length of site	375 m (+25m adaptation)
	Length of rails	1 600 m
	Tie bars	500 pieces
	Weldings	110 pieces
	Fixations	1 300 pieces
	Concrete slab	2 200 m²
	Underpour	1 600 m
	Mastic asphalt	2 200 m²

Table 1

The best offer came from a company with excellent reputation and good experience in building tram tracks. The overall costs were about €1 280 000. Cost per track and meter is around €1 600/m.

During the action weekend, 80 to 100 workers were permanently on the building site.

Construction phases and construction times

Some pictures of the constructing process are presented below:

Figure 7
Friday 7p.m. preparing for work and last tram passing

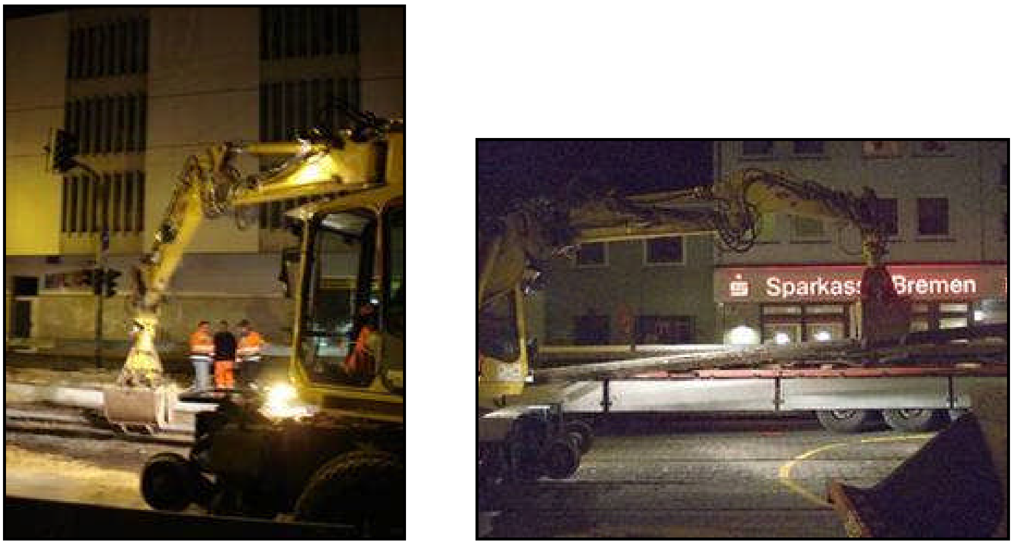


Figure 8
Load of worn rails

Figure 9
Unload of new pre-assembled tracks for further assembling (4x15m)

Figure 10
Disassembling of the base layer and preparation and compaction of formation level

Figure 11
Installation of shuttering and adjustment

Figure 12
Saturday morning: start pouring of concrete slab

Figure 13
Fix and adjust rails

Figure 14 Underpour rails

Figure 15 Pouring concrete superstructure for junction "Stader Straße" and tram in operation on Monday morning

Summary

The renewal of a 375 m long double tram track plus a 25 m transition zone (in total 400 m) during a 57 h action is possible if the circumstances and boundary conditions are as ideal as described above.

To achieve objectives the following recommendations can be made:

- all logistic activities have to be planned precisely and optimised accurately;
- all the coordination work with local authorities and residents has to be done in advance;
- weather conditions have to be favourable;
- the contractor has to be reputable, skilled workers and technicians are essential;
- the construction firm must be well equipped;
- unforeseen circumstances have to be kept in mind;
- a permanent physical presence of the employer at any time is essential.

The **length** of the track to be converted was close to what is possible and sensible from a staff and technical feasibility point of view. In future Bremen will choose rather shorter conversion lengths (up to 300 m). It has to be noted that only tram traffic was restored immediately after the weekend. The completion of the road infrastructure took another 4 weeks.

KARLSRUHE (D) - INTRODUCTION OF VIBRATION INSULATED TRACK

Introduction and Objective

The Kaiserstrasse in Karlsruhe is the track section with the most tram traffic in the entire rail network of the VBK. Seven lines of the light rail system are concentrated at the intended construction site. This means, on a realistic and existing condition of a tram traffic cycle of ten minutes, 42 tram trains operate per hour and direction. In other words, a tram train vehicle runs through this section every 85 seconds per direction. During the nightly hours the "Nightliner Concept", containing two tramlines and several bus lines operates on the tram track.

The current rail system is approximately 30 years old and at the time of its first installation, the complete development of the dual tram-train-system with higher axle loads was not foreseen. The initial selected rail system and superstructure is now too infirm for the increased loads of the dual tram train vehicles and the gone up frequency of tram trains. Therefore, the rail system is damaged. Rail failure is the result of subsidence and washouts. The current condition of the tracks is very poor and it demands high costs for maintenance and paving renewal.

Therefore, it was decided to renovate the track in this busy section. As it was important to keep the service disruption to a minimum, the choice was made to do this with CDM Modulix and Remodulix prefabricated track systems. The rails, the concrete pavement block surfaces and the kerbstones were integrated in the factory into the prefabricated track panels. The biggest part of the construction site is assembled with the Modulix system. These slabs are not intended to be removed. Two shorter sections are assembled with the Remodulix system. The Remodulix slabs will be removed in the course of the tunnelling of the Karlsruher city centre in two years. They will than be stored temporarily and then re-installed.

Description

The complete construction section in the easterly Kaiserstraße is located between the junctions Durlacher Tor in the East and Kronenplatz in the West. The section has a length of 375 m, which is a total of 750 m of track renewal. The rail tracks are in the middle of the road on a road bed separated from the road traffic by kerb stones with a height of 8 to 10 cm.

The renewal of this section was absolutely necessary; the boundary conditions for track renewal seemed optimal. Furthermore, there was the reasonable possibility to re-move and to re-install the slab tracks.

The detouring route was advanced in April 2009. Additional track connections and a second rail were installed at the detouring route.

Overall situation

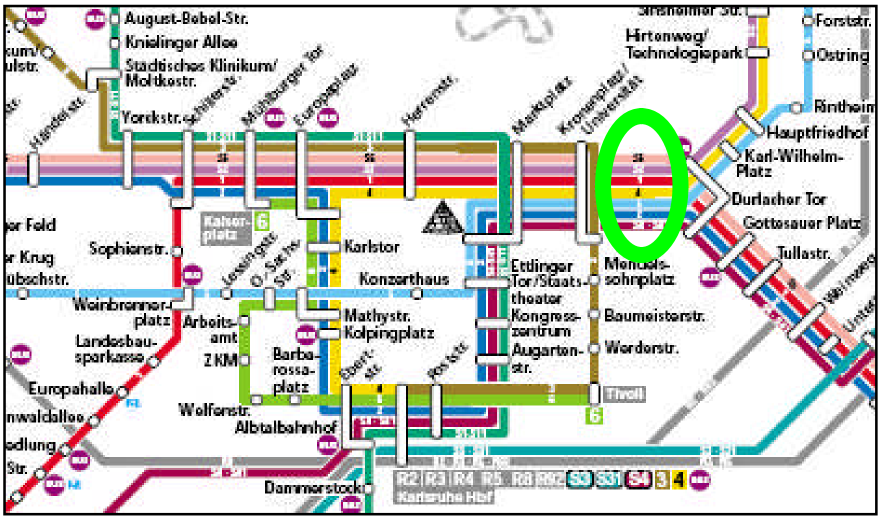


Figure 1
Extract of the KVV-line network: city centre of Karlsruhe

Local situation

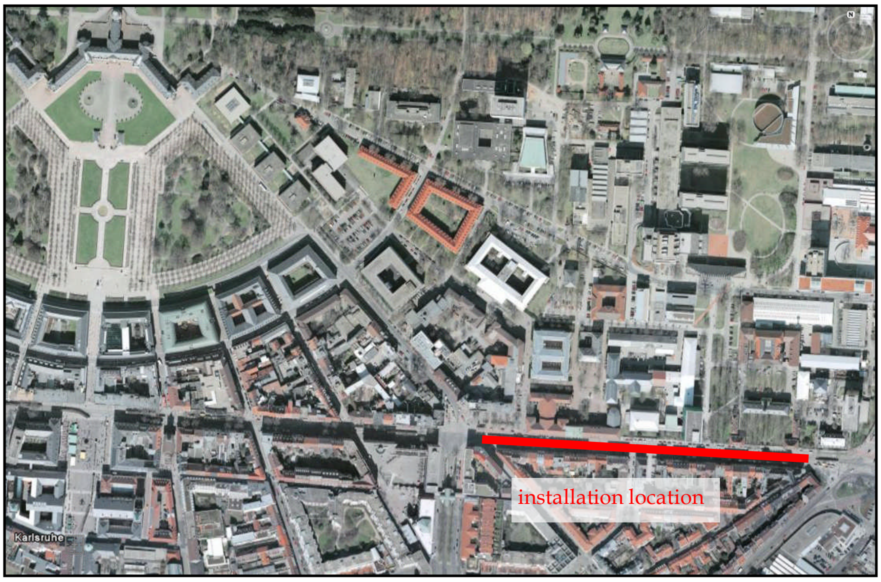


Figure 2
Building site "Kaiserstraße" in Karlsruhe

The following pictures show the track condition before renewal.

Figure 3
Uneven paving and mud pump

Mastix repair patches and drainage

Planning and coordination

A highly detailed survey was taken from the rail track in situ and the surroundings. These were the basic data for scheme planning for the VBK.

VBK and CDM develop the detailed design in close coordination regarding the survey data, the testing results and the demands of the infrastructure operator and the agency of urban planning.

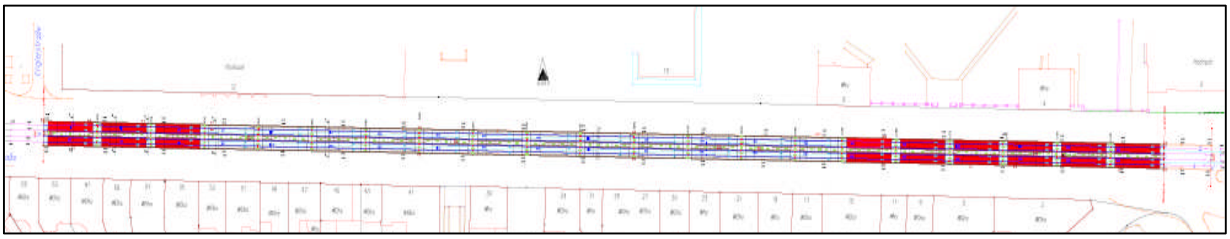


Figure 4

Scheme of track slabs elements (Remodulix-elements marked in red)

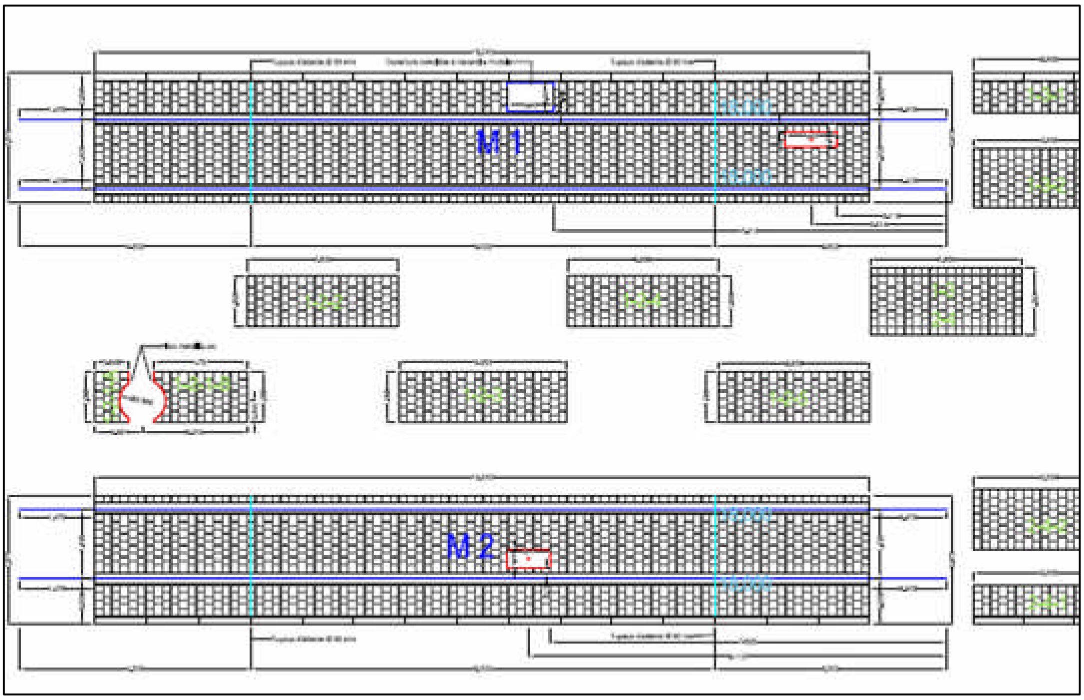


Figure 5

Track slab elements in detail

Construction phases and construction times

Some pictures of the constructing process are presented below:

Building process

Figure 6
Unloading track slab elements at the harbour of Karlsruhe

Figure 7
Removal of track

Removal of base plates

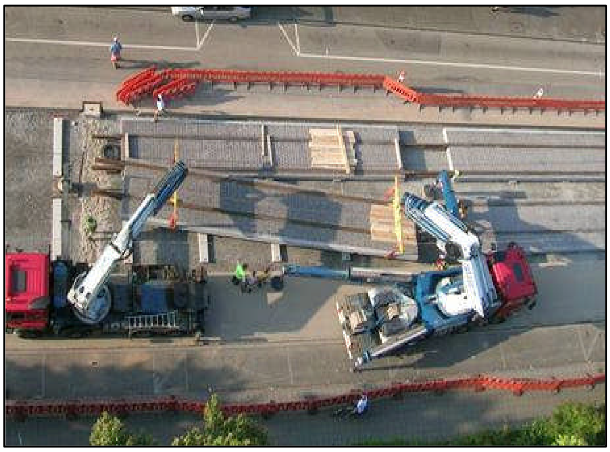


Figure 8
Assembly of track slabs

Adjustment of slab tracks with special mobile cranes under overhead wire

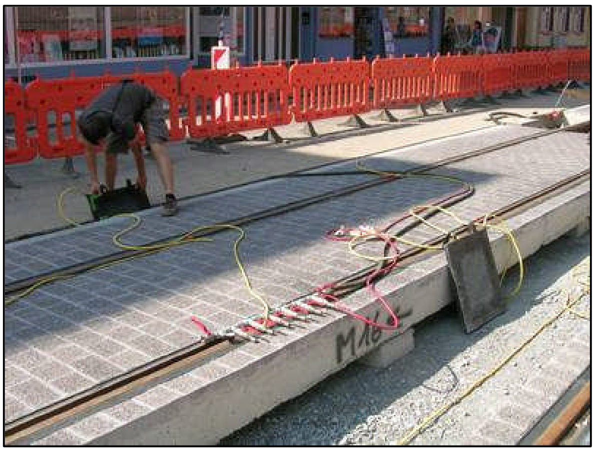



Figure 9

Pneumatic, final adjustment

Jackets at the welding zones


Figure 10

Supported slabs

Pouring grout


Figure 11

Asphalting the road edges

Construction site done

The entire track of 375 m of length was removed. Inside of the construction field, there are no tram stops.

The renewal began on August 10, 2009 and ended on August 28, 2009. During the construction period, the track section was completely blocked for tram trains. The road traffic could use this section only as a one-way street, the other direction was blocked. Pedestrians could use the parallel pavement on the side. In one direction, cyclists could use the pavement, in the other direction they had to use the road. All buildings remained accessible; all adjoining premises could be reached by car. Parking was not allowed, loading and unloading was possible during the construction period. In two days, 34 of 42 track slabs were fitted. After initial adjustment, the rails were welded. The remaining eight track slabs were assembled after completion of duct constructions

Conclusion

Overall the objectives of this installation site were achieved. 375 meters of double tracks were renewed in three weeks.

To reach this challenging objective a lot of preparation and coordination was necessary. The effort of coordination between the infrastructure operator VBK and the manufacturing company CDM was more demanding than normal. It was very helpful to make use of the experiences gained at the CDM building site in Paris.

Qualitative improvements can still be reached in the field of joints and the production accuracy of the track slabs, so the construction schedule could be further accelerated.

COST & MAINTENANCE ISSUES

LIFE CYCLE COST (LCC) CALCULATION

Considering that urban railway operations are characterized by the need for large initial investments and large annual budgets for maintenance/renewal activity, the systematic and controlled development of LCC strategies on a European level and their comprehensive implementation become a crucial issue for the economic sustainability of the urban railway business.

The scope and definition of the LCC include the definition of the parameters that have to be taken into account, and of the methodology to be used for determining the LCC.

Objective

Today's urban railway sector is imposing high demands for service quality on railway infrastructure managers. Since railway infrastructure has a long asset life, it requires both global approaches for the selection of new types of infrastructure and efficient maintenance planning to perform effectively to meet these high demands throughout its life cycle. Traditionally, maintenance decisions and the choice of new types of urban railway infrastructure have been based either on past experience and expert estimations (for maintenance decisions) and mainly investment costs (for the selection of new systems). The objective is to develop, test and provide an LCC methodology. This was necessary to evaluate the innovative products and procedures developed in the Urban Track project. At the same time it is made available free of charge to anyone interested in doing such calculations

The objectives were to obtain a generally acceptable LCC calculation method and software tool with definition of all important parameters involved for evaluating complete projects as well as for the evaluation of the introduction of innovative solutions into the network. In the project, the LCC tool was used to get a better understanding on how leading edge track system technologies can contribute to life cycle cost optimisation, given the projects specifics.

Life Cycle Costing (LCC) meeting EN 60300-3-3

Methodology of LCC

Recently, the term « Life Cycle Cost » (LCC) has been quite often misinterpreted: LCC does not deal only with maintenance or waste disposal issues. Lifecycle Cost means: « Take all expenditures into account which might occur during the entire lifetime of a product (…of a project, a process). In this analysis, it is not important if the money is spent as an initial investment (taken into account depreciation of initial investment over the years) or for ongoing and recurring activities. The relevant standard EN30300-3-3 refers to this entirety as LCC and states clearly that, besides the operational cost (mentioned as « ownership cost ») the investment (referred to as « acquisition cost ») plays an important role.

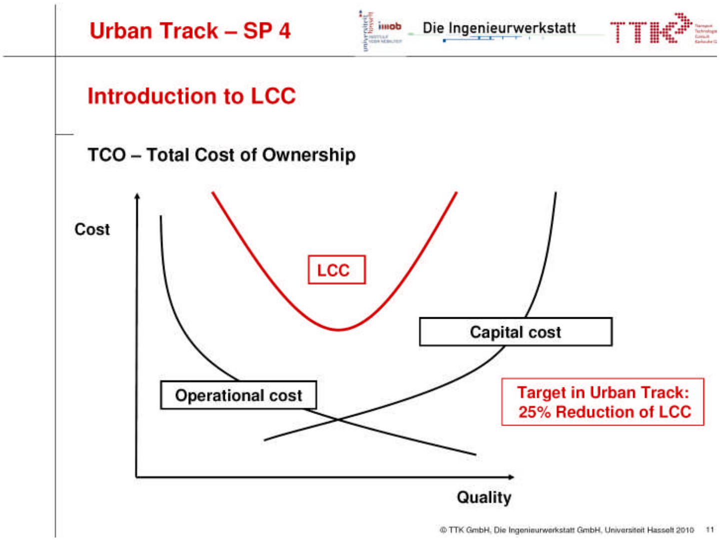


Figure 2
Introduction to LCC

Both cost elements are linked together via the quality of the product (of the project, of the process): The higher the quality is valued, the more expensive the initial investment will be, but the investor will be (or at least, should be) able to save funds in the course of the lifecycle for less maintenance, less energy consumption etc. pp.).

Basically, the individual strategy to be set up should aim at:

– Either «a maximum quality within a given LCC-budget» - a lesson to be learned is «don't buy the cheapest solution all the time».
– Or, «the quality / requirements (e.g. performance or safety) are fixed.

There are two possibilities to lower the overall cost ».The short-term oriented solution is « buy cheaper, but don't increase the maintenance », the more long-term oriented approach might be « spend a little more money in the beginning, but save a lot afterwards». As a railway business in general is looking for longer time frames than most other industries, the appropriate approach is obvious.

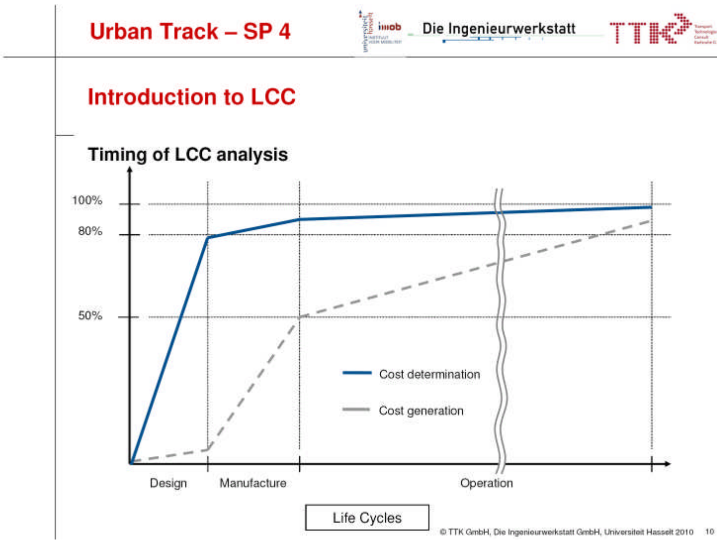


Figure 3
Timing of LCC analysis

Time schedules lead to two other important aspects: responsibility and impact.

As Figure 3 shows clearly there is a big difference in cost generation (« when and where do costs occur? Who has to bear this effort? ») and cost determination (« who is responsible, who defines, when and where which costs occur? »). Of course the biggest impacts are seen while predefining a general technical solution (e.g. driving a car is obviously more expensive compared to cycling or walking) – responsibility of the buyer. Following that the buyer (or in terms of railways: the integrated enterprise, hence the infrastructure operator) should analyze carefully the overall LCC-aspects while doing first feasibility studies or deciding about the entire system. The earlier this takes place, the bigger is the amount of « reachable cost elements » – once a person has taken the decision to drive the car, the necessity of spending money into tires, fuel, insurance and the car itself is a very logic follow-up. Since the car is designed, manufactured, provided and (at least in most cases) maintained neither by the one driving the car nor the one taking the decision to have a car at all (and which car…), the necessary solution is: « The Provider of the product must care not only about investment, but also about the subsequent expenditures of the user». The buyer has to point out, that this deems to him as an important area at all.

Experience has shown that for a light rail vehicle, 80% of the overall LCC over its average lifespan of about 15 – 20 years are determined in the design phase. For an infrastructure object the percentage of long term costs versus initial investments might be even higher, given that the lifetime of the infrastructure is much longer.

The above mentioned correlation is perfectly clear in the automobile industry – and can be considered as THE reason, why many technical innovations are driven by automobile development – long before the railway industry even thinks about it (good example : use of LEDs in rear and headlights led to significant savings in maintenance and energy consumption).

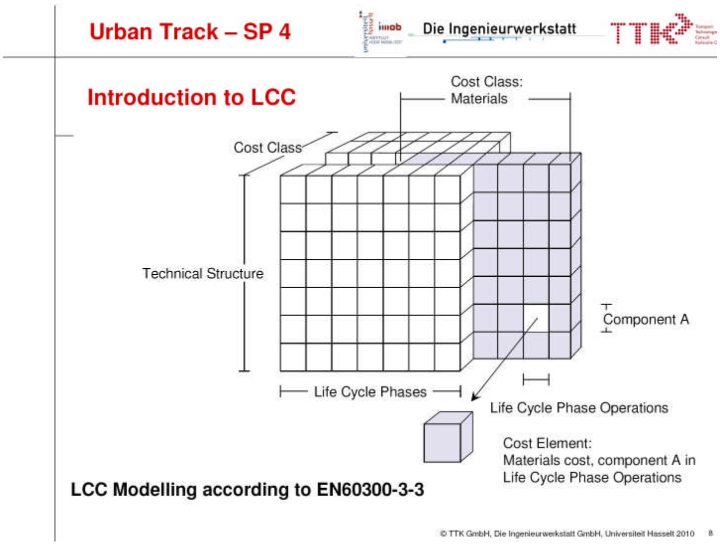


Figure 4
LCC Modelling according to EN60300-3-3

The EN standard recommends that the initial step in performing a LCC-calculation is to setup a model. (Remember: A model is a simplified picture of a complex reality). The model should be as complex as necessary (to take into account the most important contributing elements) but as simple as possible (to avoid getting stuck with lots of missing data). The Cost Element Concept of EN 60300-3-3 pictures a three dimensional matrix structuring the entirety of the total LCC: Life cycle phase, technical structure and the different cost classes. Modelling should be done right at the beginning of every project in order to generate a model, which responds to the specific needs of the individual question: there is no general applicable LCC-Model for all LCC-calculations.

LCC model for (Urban) railway infrastructure

The LCC-model for Urban Track takes into account the most important activities in rail infrastructure (e.g. investment, maintenance, energy consumption, hindrance, renewal, and disposal) in the cost classes (personel cost, material cost, energy cost, interests). The technical structure may be individually build up starting on a very high level (e.g. network, routes) top down into greater detail (e.g. rail, rail fastener, switch tongue). LCC in Urban Track means only internal costs (which are to be paid by the individual enterprise), while the external costs (which are to be paid – if any – by the society: e.g. CO2, noise, pollution) are named as Socio-Economic Cost. Both areas are pictured in the Urban Track LCC-model and can be calculated individually (and separately) and combined afterwards.

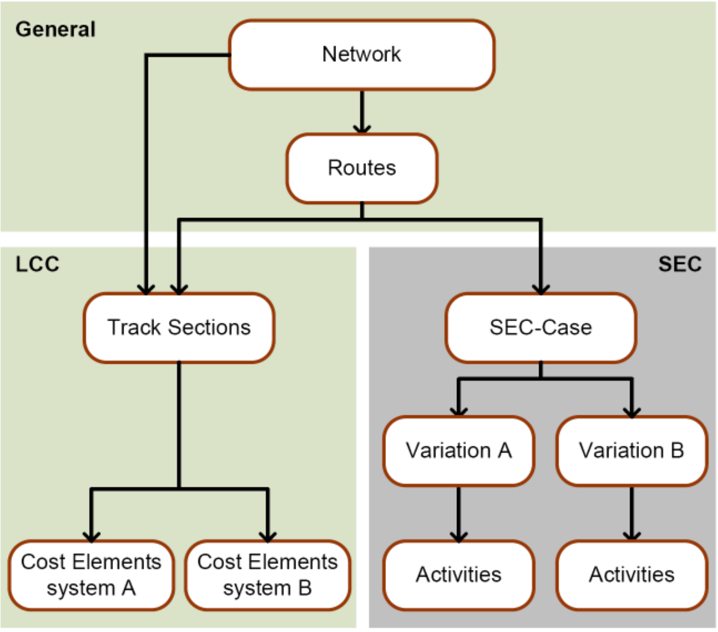


Figure 5 LCC-Model Urban Track, cost elements on LCC- and SEC-side

The Urban Track LCC/SEC-model (at least the two dimensions Lifecycle Phase and Cost Classes) is readily implemented in the calculation tool www.infracalcc.de, while the third dimension can be structured by the individual user according to his / her individual needs.

Figure 6

Log-in page and introductory page of the LCC software tool

Based on the model a web-based LCC calculation tool was developed (see Figure 6) to support the calculations carried out by the partners themselves. For further information please contact gerald.hamoeller@ttk.de.

Seville Case (Example) "Rail/road interface and finishing layer"

The objective in Seville was the installation of prefabricated track panels. Due to the fact that this was a new light rail system, information about maintenance intervals and related cost were not available. Therefore TTK developed a maintenance plan and the related LCC calculations were carried out by TTK, too.

The prefabricated panels iX Modulix

The material chosen for the interface had to be elastic with a large range of deflection without creep and permanent deformation, bond very well with steel and concrete, resist over a large temperature range, be maintenance free and protect against stray currents. In addition, the road surface had to consist of natural stones.

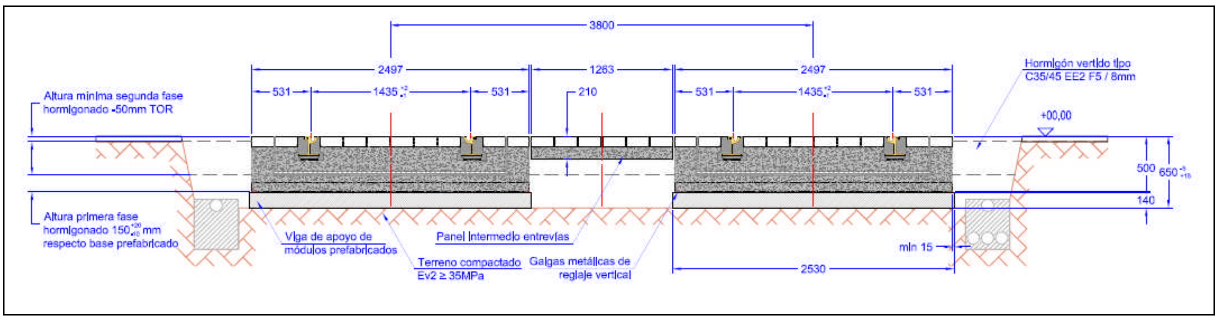


Figure 10

Cross section – iX Modulix

Reference case: Rheda city

Because iX-Modulix were built as part of a new light rail line (14 km –long), there was no a previous system to compare it to. In order to carry out an LCC analysis, it was decided to compare it to an alternative system that could have been chosen instead. Ferrocarriles de Andalucía had already analysed two other alternative systems:

- Corkelaste;
- Rheda city (which was used for the rest of the light rail line).

For the LCC calculations, it was decided to use Rheda City as the reference case.

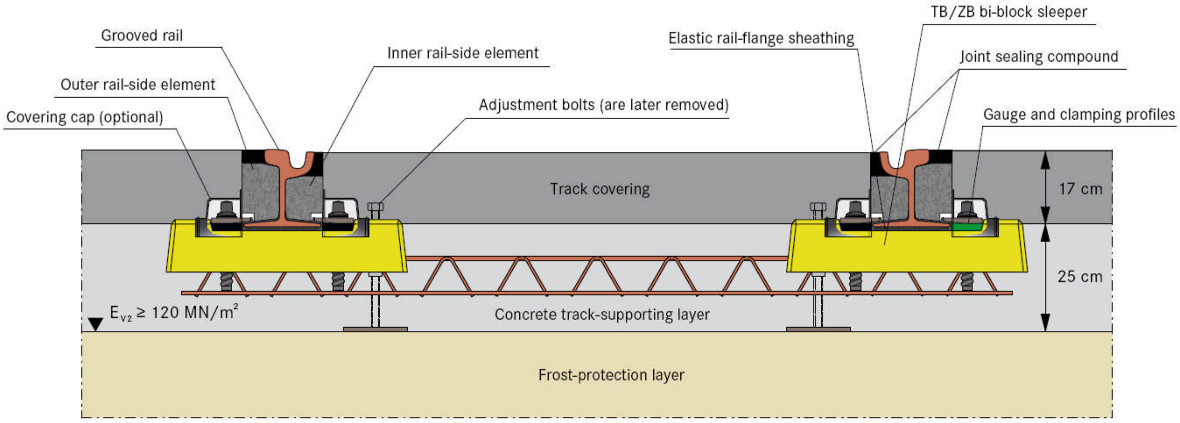


Figure 11

Cross section of Rheda City (1)[1]

Case study: Rheda City vs. IX-Modulix

In this particular crossing, Ferrocarriles de Andalucia selected paving- stones as track cover for the IX-Modulix. Therefore, the reference case must also have the same track cover.

LCC Parameters and results

The comparison between Rheda City with a track cover of paving-stones and IX-Modulix with a track cover of paving-stones with concrete cover would is made for 72 m of single track.

The following boundary conditions have been applied for the LCC calculation of both study cases:

Wage rates:	Engineer:	48 €/h
	Technician:	30 €/h
	Skilled labour:	19 €/h
Energy cost:	N/A	

Defined Life Cycles of the tested systems:

- Rheda City: 30 years
- iX-Modulix: 30 years

[1] (1) Source: Rail.one; Rheda City Brochure

Period under consideration: 50 years

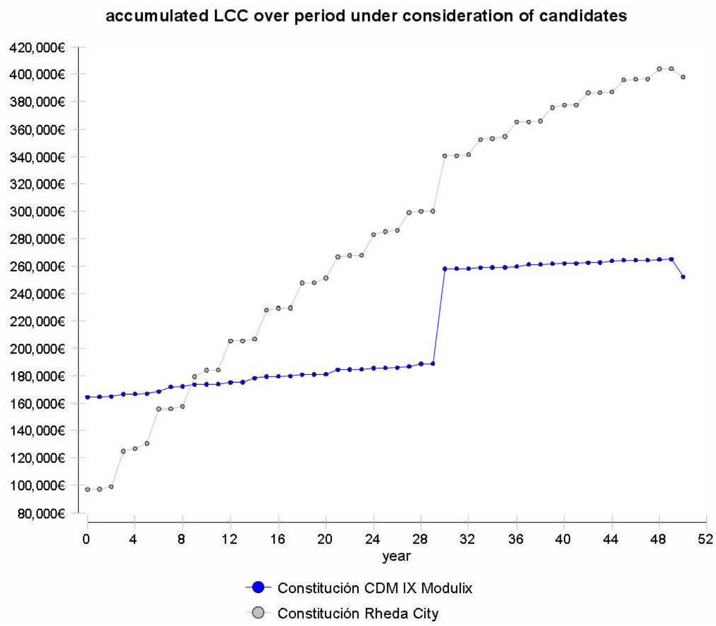
Financial aspects:
- Interest rate: 5%
- Inflation rate: 2%

The considered activities and LCC related cycles of the studied systems are the following:

Activities/Cost elements	**Frequencies "Reference case" "Rheda City"**	**Frequencies of new system "iX-Modulix"**
Construction and Investment phase		
Construction and investment of track	Year 0 (lifetime 30 years)	Year 0 (lifetime 30 years)
Operation and Maintenance phase		
Inspection for Safety	Once every six weeks	Once every six weeks
Drainage cleaning	Every three months	Every three months
Rail cleaning	Every two months	Every two weeks
Rail grinding	Every two weeks	Every two weeks
Renewal of joints	Ever three years	---
Paving-stones cover retouch and milling	Every three years	---
Paving-stones renewal	Every seven years	---
Welding of joints	Once after fifteen years and twice between years 20 and 30	Once after fifteen years and twice between years 20 and 30
Welding of rail breaks	Once after fifteen years and twice between years 20 and 30	Once after fifteen years and twice between years 20 and 30
Removal and Disposal phase		
Removal of track infrastructure	Not considered	Not considered

Table 1: Considered maintenance activities of Rheda City and iX-Modulix

Total results of LCC net present values for each system of scenario A (broken down by activity):



candidate	activity	total cost [€]
Constitución CDM IX Modulix		
Constitución CDM IX Modulix	Adjustment	25,241 €
Constitución CDM IX Modulix	Cleaning	5,579 €
Constitución CDM IX Modulix	Inspection by experienced personell	207 €
Constitución CDM IX Modulix	Installation	220,117 €
Constitución CDM IX Modulix	Machine grinding	299 €
Constitución CDM IX Modulix	Welding	560 €
Constitución Rheda City		
Constitución Rheda City	Adjustment	239,564 €
Constitución Rheda City	Cleaning	5,579 €
Constitución Rheda City	Inspection by experienced personell	207 €
Constitución Rheda City	Installation	129,367 €
Constitución Rheda City	Machine grinding	299 €
Constitución Rheda City	Renewal	22,235 €
Constitución Rheda City	Welding	560 €

Total Net Present Value (NPV) Reference prognosis (Rheda City):	397 810,00 €
Total Net Present Value (NPV) new system (iX Modulix) Prognosis:	252 002,00 €
% **Reduction** in NPV:	36,7%[2]

Table 2: Overview of NPV for iX-Modulix and Rheda city (reference)

The results of the comparison of both track systems with a paving-stone surface show that the LCC of iX Modulix is some 37% lower than Rheda City. The main reason of this important difference lies in the selected type of track cover: paving stones. Even though the installation costs of iX Modulix were much higher than those of Rheda City (+70% difference), the maintenance costs of Rheda City with this particular cover were extremely high (nearly eight times higher than the maintenance costs of iX Modulix with the same cover – see “ADJUSTMENT”).

[2] Reduction of NPV in% relative to Reference Case value.

These results corroborate results from the tests made earlier in the project on the Circular Testing Machine where track systems with different surface types were tested. Three surface types studied were: asphalt (in two variants), pavement (in three variants) and concrete (in three variants). During the test, a wheel ran 1 million times over the test bodies, representing a 10 year service cycle. The only track covers that did not withstand the load were the pavement structures comprising natural stones secured with an elastic joint sealing compound.

The lesson to draw from this experience is that track systems with a paving-stones cover do NOT behave well in particularly high traffic corridors or crossings and should not be implemented in such areas. Maintenance costs in such cases are significant.

Conclusions

The development of the LCC methodology and the associated on line calculation tool is a major step forward in making decisions regarding which track system to install and how to maintain it. However, and although significant steps have been made, the awareness of the application much reach a broad audience. Within the research community, the study of LCC and RAMS analysis and their applications on urban railway infrastructure is nothing. Many thesis works, publications and studies have been made on this subject for many years. However, within the community of European urban track infrastructure managers, LCC approaches are not as common. The Urban Track project, and especially SP4, has tremendously increased the awareness of LCC approaches and methodologies within the Urban Track consortium and the associated user groups Networks of Operators and Industries. The team is very confident its work has had a very positive impact on these partners and that the multiple advantages of the application of LCC approaches, especially for decision-making, have been disseminated.

Nevertheless, LCC remains a complex and thus challenging issue. Indeed, in order to carry out the analysis, it is important to have access to all specific cost element information depending on the level of analysis to be carried out. This was the number one issue and number one limitation for all calculations throughout the four years of research. The more detailed and thorough the information regarding the costs of installation, maintenance, operation and removal, the more accurate the LCC results become. Through the many discussions with the LCC calculators, we learned that very few calculators disposed of detailed maintenance costs. For the most part, assumptions regarding these costs had to be made or general costs for overall activities were used as input in the LCC software. This LCC tool is an expert-oriented tool. For the proper use of this tool and for carrying out both “qualitative and quantitative” LCC analysis, it is very important to have the correct cost element information at the right information level. In the practical cases studied within the project, we have seen that this was a big obstacle, as key data regarding cost elements was sometimes either missing or sometimes the LCC analysis was carried out on a too global level (without really detailing for instance all the necessary maintenance and operations activities).

SOCIO-ECONOMIC IMPACTS OF RAIL TECHNOLOGIES

The aim of the socio-economic assessment methodology is to map relevant impacts of different technologies in order to make a well-funded decision for a certain rail installation technique. Based on literature and interviews with operators, municipalities, experts and other stakeholders we have defined a set of impacts varying from direct (building site) to indirect (global) and phase: construction, operation and maintenance/refurbishment (Figure 1).

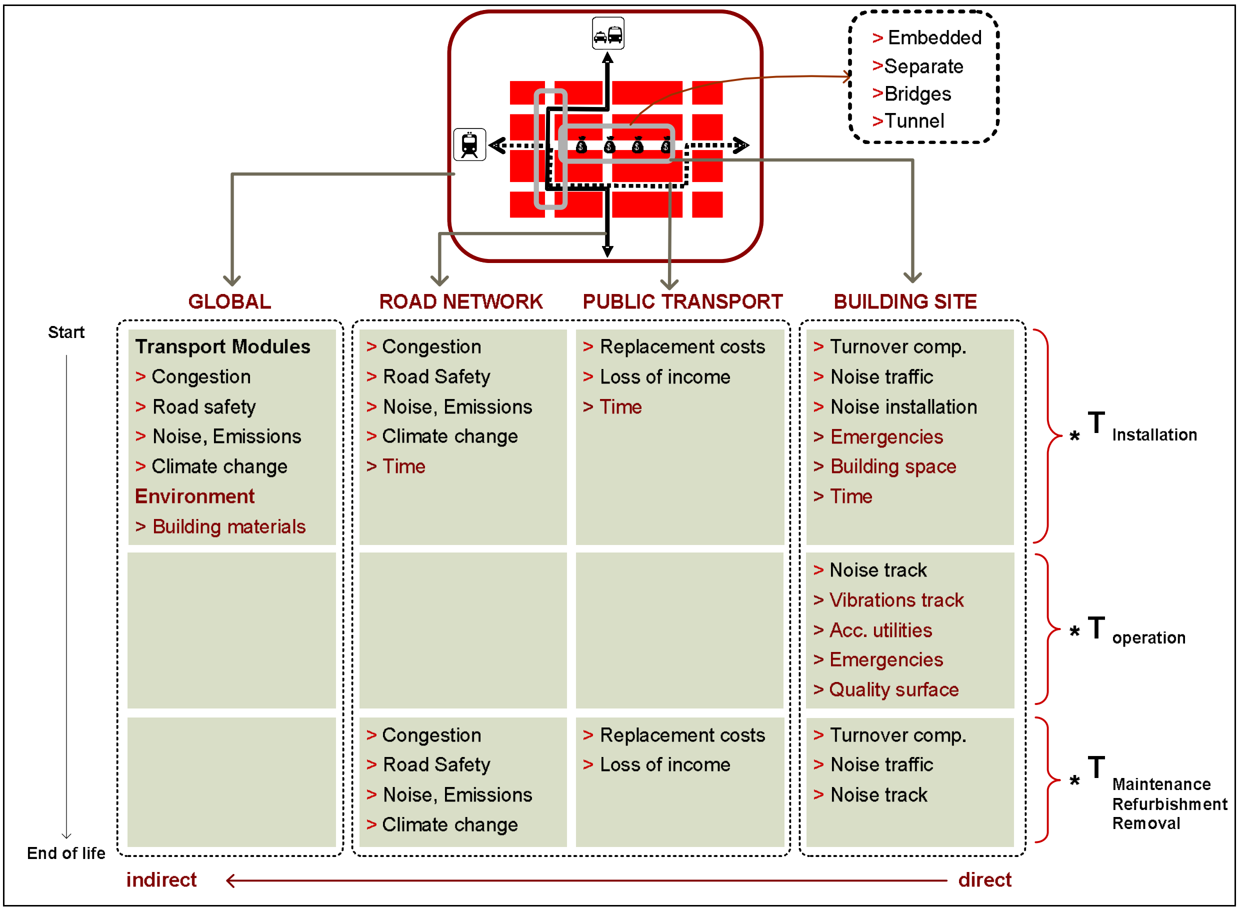


Figure 1
Overview of Quantitative (black) and Qualitative (red) impacts

Monetized impacts

With the choice of indicators, we have tried to look for effects that can be 'manipulated' or 'affected' by the developers of the rail technologies. Indicators like 'noise' and 'vibrations', but also the environmental impact of the building materials are directly linked to the technology. Also the location influences the socio-economic impacts. The impact on the road network for example will be affected by the construction time and the building space needed. This means that changes in the design or the installation technology have a direct measurable effect on those indicators. The calculation of each indicator consists of three components: a) location characteristics like traffic volume and amount of residents and businesses, b) rail technology characteristics like time needed for installation, noise and vibrations during operations and hindrance for public transport and traffic, c) monetary values.

The monetary values are based on European-wide studies with a high acceptance within the professional community. For some indicators like road safety or emissions, a lot of European research is available, but for other impacts like the impact on turn over, it is not possible to find research that deals with several European countries at the same time or with several cities within one country. For internal consistency we have mainly used the IMPACT study (Infras/IWW) and HEATCO (Schreyer, Schneider et al. 2004; Bickel and Rainer 2005; Maibach, Schreyer et al. 2007).

Because most monetary values in European research projects use 2000 as reference year, we have done the same.

Figure 2 gives an impression of the impact of works on the building site and the road network. In the following paragraphs, we describe which monetary values we have used for these impacts as well as for transportation of modules. More details about the calculations can be found in the main report about the methodology (de Jong and Declercq 2010).

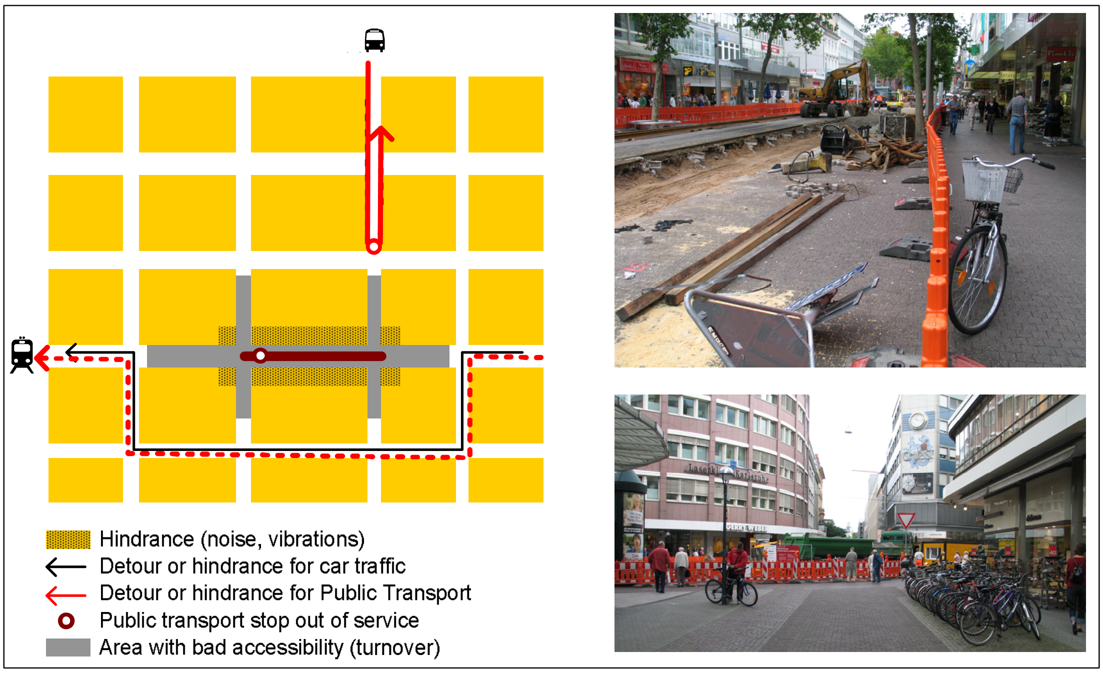


Figure 2 Impact of installation of tracks for building site and detour (PT, cars)

Building Site

Turnover

Most businesses will lose clientele, and therefore have a loss of turnover due to construction works outside. An important factor is the accessibility of the location for cars and pedestrians and the possibility to reach the location by car or public transport. Within Europe, there is no uniform way to value damage because of construction works. Very often, individual businesses have to negotiate with the local authorities about compensation for the loss of income and in a lot of cases they also have to prove this loss of income in order to qualify for compensation. Because of lack of agreement about compensation fees within Europe and even within individual countries, we have based our values on the Belgian law on 'income compensation of businesses during construction works' (Belgium Federal Government 2007).

According to this law a small business has the right to claim a compensation of 70 € per day if it is not possible to park the car in the vicinity and if the accessibility for pedestrians is not good but compensation will only be given if the works last at least 14 days. In our methodology, we do not use this limitation and we added the condition that compensation will be paid if there is no public transport stop within 200 meters during the works.

Noise cost due to less traffic

As there usually is less traffic on the construction site during the works, the noise costs will be lower than normal. Noise costs are composed annoyance costs based on preferences of individuals, and health costs based on dose response figures (Maibach, Schreyer et al. 2007). The marginal noise costs decrease with increase of traffic, which means that the costs of additional vehicles are lower when there is already a certain traffic volume. Traffic noise is measured on a logarithmic scale: halving or doubling the traffic volume in a situation without other noise, will cause a change of 3 dB. Because of existing background noise the effect of additional traffic can be lower than the average costs for medium to high traffic volumes. The higher the background noise, the lower the marginal costs because of additional vehicles. This is the reason that the costs per kilometre are subdivided in thin and dense areas. The values provided by INFRAS/IWW (Schreyer, Schneider et al. 2004) are representing a useful European average based on state of the art noise exposure formula, input values and level of differentiation.

Noise costs due to construction

Construction activities often produce extra noise and consequently annoyance. To valuate the noise costs due to construction works we use a value that reflects the changes in noise that are experienced by people. This means that we use the changes in noise level at the facades of the houses. Different researches have been carried out, mostly based on stated and revealed preferences of individuals (Nijland, Van Kempen et al. 2002; Schmedding, Gringmuth et al. 2005). Based on literature research of Navrud (2002) the Working group on Health and Socio-Economic Aspects (2003) recommends to use the median value change in noise perceived by households of 25 € per dB (L_{den}) per year. This value should be applied at all initial noise levels and regardless the size brought about. The noise levels during the different phases of the works have to be provided by the developer of the technology, but can also be measured on the street.

Public Transportation

Replacement costs

Public transport companies often use 'standardized' prices for replacement transport, depending on amount of vehicles that have to be replaced and available alternatives. In the calculation of the socio-economic effects, we assume that the service level of the public transport should be maintained as good as possible which means a replacement service or detours resulting in longer travel time, which may cause inconvenience for the passengers and eventually loss of passengers. As long as the works do not last very long we assume that there will not be a shift in modal split. Replacement costs are often based on Vehicle Revenue Hours (VRH): the hours a vehicle travels while in revenue service. A VRH contains the costs for the vehicle, the kilometres and personnel costs and can be used to assess the exploitation costs. The Dutch Ministry of Transport, Public Works and Water Management (2005) carried out a comparative research about the use of Vehicle Revenue Hours within Europe in order to define indicators for public transport in the Netherlands. The costs per VRH range between 77 € and 100 € for small buses. We took the upper boundary, as we do not know whether the replacement service will be carried out with small or articulated buses, which have a higher cost per VRH. In function of the calculations, we converted the costs per VRH into costs per kilometre. Based on an operational speed of 20 km/h, the cost per kilometre is 5 €/vkm. This value corresponds with values used by the Belgium public transport company De Lijn which charges between 3 and 5 € per vehicle kilometre. The costs per VRH for trams vary between 150 and 200 € which means between 7,5 and 10 € per km. For trams, we also use the upper boundary. 20 km/h is on the high end, for a good system, and therefore on the save side. As the values may differ per country and even per city, it is possible to adjust these costs as part of the location characteristics.

Loss of Income

This impact is based on the amount of stops that are temporary out of service and the percentage of passengers without replacement service or other public transport stop within 250 meters walking distance. If the network is dense, there will be more alternatives and this value will be lower. In some cases, a whole line or part of a line is taken out of service because of works and there is no detour or replacement service foreseen. With the calculation of the loss of income, it is perfectly possible to calculate the impact of those situations. As average fee per ticket, we have taken a German average price per passenger of 0,70 € but this value can also be adjusted as part of the location characteristics.

Detour of traffic

When we calculate the socio-economic costs on the detour, we deal with extra kilometres and an increase of traffic volume on the detour route. For the calculation of the detour costs, we have therefore used the marginal costs as they are based on the costs induced by an additional vehicle using the road network.

Marginal Congestion Costs

The IMPACT study (Maibach, Schreyer et al. 2007) distinguishes three levels of costs, depending of the type of urban area. The type of urban area has to be chosen as a location-specific attribute. The costs per vehicle kilometre are 6 times higher in city centre streets of large urban areas than on local streets in small and medium urban areas. We have chosen to calculate with the worst-case values. For small and medium urban areas we calculate with 0,5 € per vehicle kilometre (urban collectors and local streets) and for large urban areas we differentiate between centre and cordon, respectively 3,00 and 1,00 € per vehicle kilometre.

Marginal Road Safety Costs

For the socio-economic calculations of the road safety effect, we used the values for marginal accident costs as we deal with additional traffic on an existing road. Because of increased traffic, speed may slow down which can result in a lower risk and lower cost values per kilometre. The mean marginal accidents costs for cars on urban roads in 11 European countries according to the INFRAS/IWW study of 2004 would be 75,17 €/1000 vkm (bandwidth from 9,8 €/1000 vkm in Finland to 156,6 €/1000 vkm in the Netherlands). The mean value for cars on urban roads in the EU_{15} countries according to the IMPACT study (Maibach, Schreyer et al. 2007) would be less, that is to say 52,08 (bandwidth from 26,1 for the UK to 108,1 for Luxemburg). The figure for Heavy Duty Vehicles (HDV) on urban roads is rather high compared to motorways and other urban roads; in some cases a factor 20 higher. The percentage HDV is a location-specific attribute.

Marginal Noise Costs

The marginal noise costs for the detour are calculated the same ways as the impact of less traffic on the building site.

Marginal Air Pollution Costs

The UNITE project (Suter, Sommer et al. 2002) is considered as one of the most important studies in the field of air pollutions costs. Based on the 'impact pathway approach' as developed by the ExternE Project (Bickel and Rainer 2005) the costs of emissions were calculated. The 'impact pathway approach', looks at the whole chain from causation of impact, transport and transformation into reception. The costs are based on the impact of PM10 on health. The emission of PM10 is influenced by the transport mode and the amount of kilometres. A longer route will therefore have effect on the air pollution costs. In general, the marginal air pollution costs are more or less the same as the average air pollution costs since the dose response function is a linear function.

Marginal Climate Change Costs

Greenhouse gasses cause damages on a global scale like changes of temperatures and rainfall, extreme climate events, crop loss and health effects. The transport sector is responsible for a very important share of the CO_2 emissions in Europe. Other greenhouse gasses like N_20 are converted into CO_2 equivalents and are also taken into account. The costs of CO_2 emissions are calculated by multiplying the amount of CO_2 by the shadow value per ton. This value depends strongly on the objective of climate change policy. INFRAS/IWW (Schreyer, Schneider et al. 2004) made calculations with a minimum shadow value of 20 € per ton CO_2 and with the maximum value of 140 € per ton CO_2. The minimum shadow value can be seen as a lower boundary for short-term targets as defined in the Kyoto protocol. The maximum value is more ambitious and follows the IPCC long-term targets. For the calculations of the socio-economic costs, we used the costs based on the maximum shadow values. But even this value is low compared to the value Germany uses which is about 231 € per ton CO_2.

Transportation of Modules

Most fast installation methods use prefabricated elements that are produced somewhere else and only have to be installed at the building site. Apart from advantages, the use of prefab systems also can result in more transportation costs as the prefab elements are often made in a special factory. A lot of operators prefer to have the same type of rails and pavements throughout their whole network which means transport to the factory. The transport of modules to the building site requires in most countries special transport with safety vehicles following the truck. We calculate the extra costs due to transportation of material between the 'central storage place' and the factory. Costs from fuel consumption are not taken into account as these costs will be passed on to the price of the product and therefore be included in the LCC calculations. The final amount is a sum of the costs caused by marginal congestion costs (trucks), marginal road safety costs (trucks), marginal noise costs (trucks, trains), marginal air pollution costs (trucks, trains, ships) and marginal climate change costs (trucks, trains, ships) based on the IMPACT study (2008). For the costs of trucks, we use values that are relevant for large trucks (HDV > 32 tons) which comply with the EURO-3 norm. When costs are differentiated according to area and road type, we assume that trucks use each type of road and area a certain percentage of the time (for more details see below). For rail transport, a distinction is made between diesel and electric trains, while for inland navigation costs differ according to the size of the ship.

Operation

Noise Costs

Research of Griefhahn as part of the Silence project (Griefahn, Gjestland et al. 2007) and Petz and Stenman as part of the QCity (Petz, Stenman et al. 2006) project shows that the effect of noise produced by rail traffic is relatively low compared to background noise of the city and often considered less annoying than noise caused by car traffic depending on the spectrum of the noise and the situation. But as stated before, we do take noise into consideration as it always has an impact. The European project BUGS, Benefits of Green Spaces (De Ridder 2004) indicates that the type of ground cover has an impact on the noise propagation, but the effects at shorter distances is that limited that we did not take it into account. We did not find useful monetary values for noise in different traffic situations so we used the same values as those for noise on the building site due to construction works. Noise during operation is caused by passing trains and is rather complicated to define, as the noise can be direct, transmitted through the air or ground borne. The impact of noise during operation can be calculated as an absolute number, but also as a relative measure based on the difference of noise levels between two systems. The amount of decibels caused by the passing trains has to be defined by an expert, which can be the developer of the track system. A common way to describe the amount of sound caused by passing vehicles is the Sound Exposure Level (SEL) (Hanson, Towers et al. 2006).

Qualitative impacts

It turned out to be almost impossible to find widely accepted monetary values for all impacts that were considered as important by the developer of the technologies, the city or the public transport companies. This is not surprising as monetizing impacts is one of the main challenges of the assessment of socio-economic costs and benefits (Boardman, Greenberg et al. 2006). The important impacts that we could not monetize are left out of the quantitative model, but are incorporated in the qualitative part. The qualitative aspects are scaled in five levels apart from vibrations, which has three levels. Some impacts are not relevant and can be turned of in the overall qualitative assessment. The impacts are briefly explained in the following section.

Qualitative impacts during works

Time

The longer the works take, the larger the impact of the hindrance. If the street in front of a shop is closed for only one week, the impact will be much less, than if it were closed for several months, as customers will change their behaviour and might not come back after reopening. Also a detour will often cause more hindrance as it takes longer.

Construction area usable for emergencies during the works

Every location should be reachable for emergencies, also during works. For some systems, this is easier than for others. In some cases, this impact is not applicable, for example for the construction of a crossing where both sides of the street are still accessible.

Building space needed above ground during the works

Depending on the system, there is a certain amount of space needed. Construction systems, with a lot of manual work normally do not need a lot of space. Installation of large prefab elements on the other hand requires a lot of building space.

Qualitative impacts during operation

Underground utilities accessible

In some cities underground utilities like sewer systems and glass fibre cables have to be accessible, for example when it is not possible to reroute them before installation of the track system. In other cases, this item is not relevant, for example, when there are no underground utilities.

Usable for emergencies during operation

In some cases, the tracks are part of the emergency routes of the city. In those cases, the tracks should be usable for emergencies.

Quality of the surface

The quality of the surface during operation is meant as the extent to which the quality that is installed stays the same over time. This indicator measures whether the same quality is maintained half way and at the end of the life cycle.

Vibrations

In contrast with the other qualitative impacts is this one scaled on five levels: no impact, little impact, moderate impact and serious impact, severe impact based on the Transit Noise and Vibration Assessment FTA manual to assess the impact of noise and vibrations (Hanson, Towers et al. 2006).

Environmental impact of building materials

Life Cycle Assessment deals with the environmental impact of the materials used from cradle to grave. There are different databases and methodologies to calculate those costs (Environment Australia ; EUROSTAT 2001; EUROSTAT 2002; Heijungs 2003; de Bruyn, Sevenster et al. 2004; Sørensen 2004), but most of them are not publicly available or require a lot of own calculation work. An exception can be made for the Ecolizer of the Flemish waste company OVAM (2005) which is based on the Eco-indicator 99 (Goedkoop and Spriensma 2001) and a manual of the Dutch Ministry of Housing, Spatial Planning and the Environment (2000). The Ecolizer is developed as a tool for the building industry to assess the ecological impact of their constructions. The Ecolizer is user-friendly and with the volume and the weight of the materials, the amount of eco-points (mPt) can be calculated. One mPt or millipoint represents one thousandth of the yearly environmental load of one average European inhabitant.

The Karlsruhe example

The location

The city of Karlsruhe has about 289 000 inhabitants and can be seen as a medium size city. The Kaiserstraβe is an important access of the city centre and the university area when coming from the east. On average days about 8 600 cars pass this section of the Kaiserstraβe between 6 am and 8 pm Because of the works, only one lane was available for cars and during the first three phases, it was not possible to park at any sides of the road. Cars driving in the direction of the city centre had to follow a detour. Although the building site is an access route of the pedestrian area, the neighbourhood is not very busy with traffic. The total length of the test site is 378 meters consisting of 2 times 9 modular elements of 18 meter each. A traditional slab track system has been taken as a reference system for the calculations.

The works had a considerable impact on public transport, as the average frequency is 46 vehicles per hour. Some lines had a detour and other lines where shortened and passengers had to continue on another line. Because of the dense public transport network of Karlsruhe, for most passengers it did not cause a lot of problems. During the works, two stops, which were lying close to each other, were out of service, which had impact on residents and businesses in the vicinity of those stops because of the reduced accessibility of public transport. For bicycles and pedestrians though, it was possible to use both sides of the street, which compensated a bit for the reduced accessibility by public transport and car. Figure 3 gives an overview of the impact of the works for car traffic and public transport.

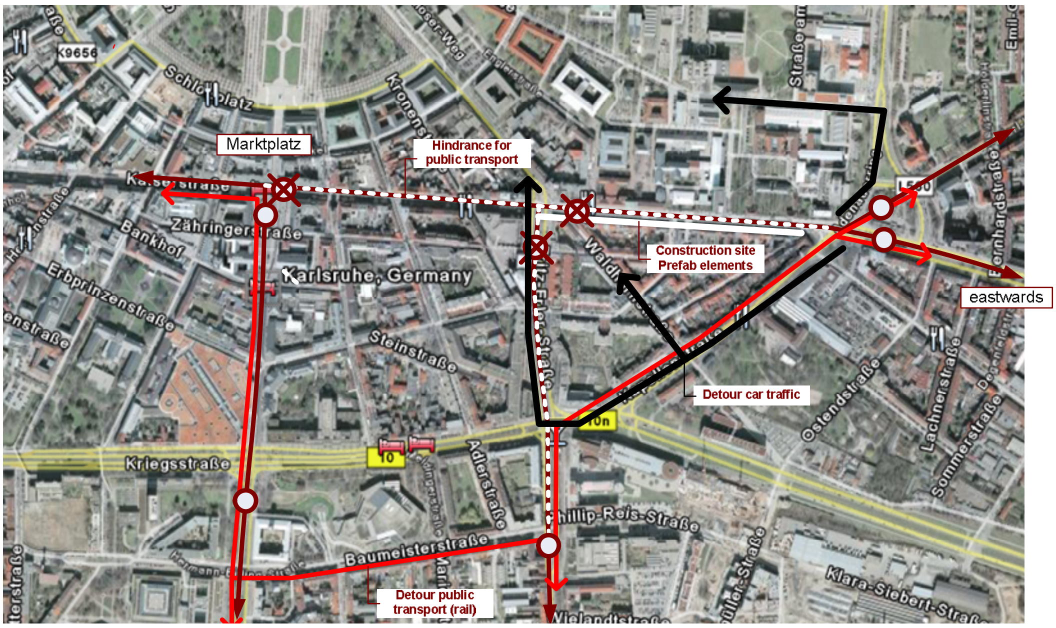


Figure 3
Overview of the Kaiserstraβe in Karlsruhe and the impact of the works

The amount of households affected by the works is estimated based on field counts and google earth. About 100 household and 52 shops situated in the immediate vicinity of the building site will be affected by the works because of decreased accessibility for pedestrians and the temporary closure of tram stops. We included business in the vicinity of the tram stop that had to be closed during the works as they will have fewer customers because of reduced access by car and public transport.

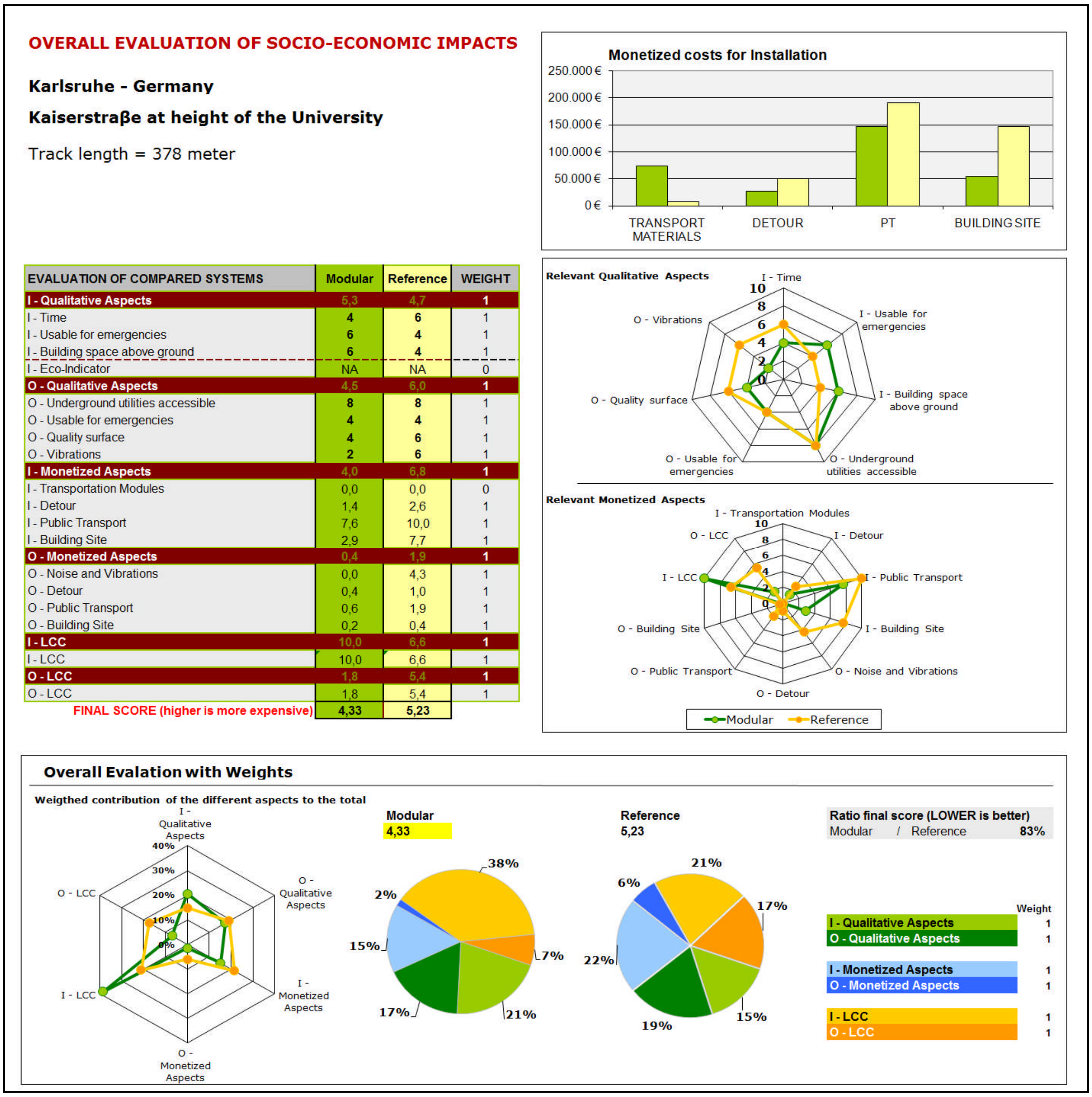
Socio-economic impacts

The total installation has been carried out within the planned two weeks. The different phases each had their consequences for car traffic, public transport and hindrance because of noise. The prefab elements were assembled in the south of Belgium and transported by ship to Karlsruhe and transported on trucks to the installation site and to be placed Figure 4). This shows immediately that the building site has to be large enough, contrary to the traditional system were just the width of the tracks serves.

Figure 4

Installation of Modular elements (left) and traditional system (right)

Figure 5 shows different socio-economic costs for the modular and the traditional slab track system. The graph in the right upper corner shows one of the major advantages of the tested modular system: the very fast installation time having a positive impact on the costs caused by detour for car traffic, less public transport and the hindrance for adjacent functions and therefore leading to lower monetized socio-economic costs. The transportation of the prefab modules is an important socio-economic cost compared to the reference system, mainly because of the distance over which the modules had to be transported. The choice of developer to transport 42 modules over water contributed to a significant reduction of the socio-economic cost caused by transport of the modules. During operation of service, the most important socio-economic advantages are caused by a lower frequency of maintenance activities and an expected reduction of hindrance caused by noise and vibrations.



EVALUATION OF COMPARED SYSTEMS	Modular	Reference	WEIGHT
I - Qualitative Aspects	5,3	4,7	1
I - Time	4	6	1
I - Usable for emergencies	6	4	1
I - Building space above ground	6	4	1
I - Eco-Indicator	NA	NA	0
O - Qualitative Aspects	4,5	6,0	1
O - Underground utilities accessible	8	8	1
O - Usable for emergencies	4	4	1
O - Quality surface	4	6	1
O - Vibrations	2	6	1
I - Monetized Aspects	4,0	6,8	1
I - Transportation Modules	0,0	0,0	0
I - Detour	1,4	2,6	1
I - Public Transport	7,6	10,0	1
I - Building Site	2,9	7,7	1
O - Monetized Aspects	0,4	1,9	1
O - Noise and Vibrations	0,0	4,3	1
O - Detour	0,4	1,0	1
O - Public Transport	0,6	1,9	1
O - Building Site	0,2	0,4	1
I - LCC	10,0	6,6	1
I - LCC	10,0	6,6	1
O - LCC	1,8	5,4	1
O - LCC	1,8	5,4	1
FINAL SCORE (higher is more expensive)	4,33	5,23	

Figure 5 Monetized socio-economic costs for installation

As not all socio-economic impacts can be monetized, we also looked at qualitative impacts. The upper part of the table and the upper spider graphs show the qualitative aspects. During installation, one of the advantages of the prefab installation is the fast installation time causing less hindrance and annoyance for residents. The prefab elements are not stored or assembled at the building site but are placed immediately after arrival which means that there has to be enough space for large trucks with cranes. For some locations, this might be a disadvantage, especially when there are a lot of trees, lampposts or overhead wires. But on the other hand, it means that the space next to the rail bedding is relatively empty which can be an advantage in case of emergencies. Both the performance of the system and the quality on the long term is expected to be higher than for a traditional system because of the controlled production of the elements and reduction of mistakes at the installation phase.

The table at the left site compares the qualitative and quantitative aspects as well as the life cycle costs that have been calculated with a different program on an equal scale from 1 to 10. The modular system is expected to be two times more expensive, but maintenance is expected to be cheaper. Each individual element can be switched on or off depending on relevance and each block of impacts can get a weight to differentiate the importance. In this case, transportation of modules is switched of and not taken into account in the overall evaluation as can be seen in the spider graph at the right hand. If we look at the overall evaluation, the modular system has a lower score, meaning lower costs.

Conclusion

Developing the methodology and applying it on validation sites made clear that socio-economic aspects do play an important role in installation and maintenance activities of urban rail systems. The methodology provides insight in the cost drivers and can play a role in a decision making process. The possibility to set priorities by assigning weights and switching off non-relevant items allows a customization to the local situation and shows at the same time which elements are taken into account. For any outcome, it is relatively easy to trace back those impacts that have the most important effect on the score and to look for improvements.

Figure 6 shows a comparison of the socio-economic costs and the LCC values that have been calculated with InfraCalCC.

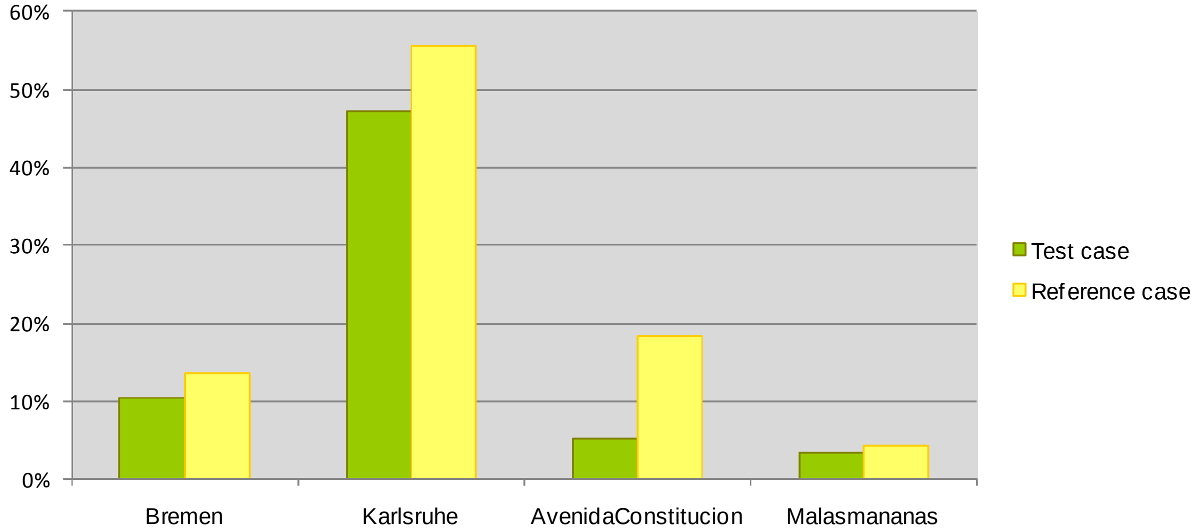


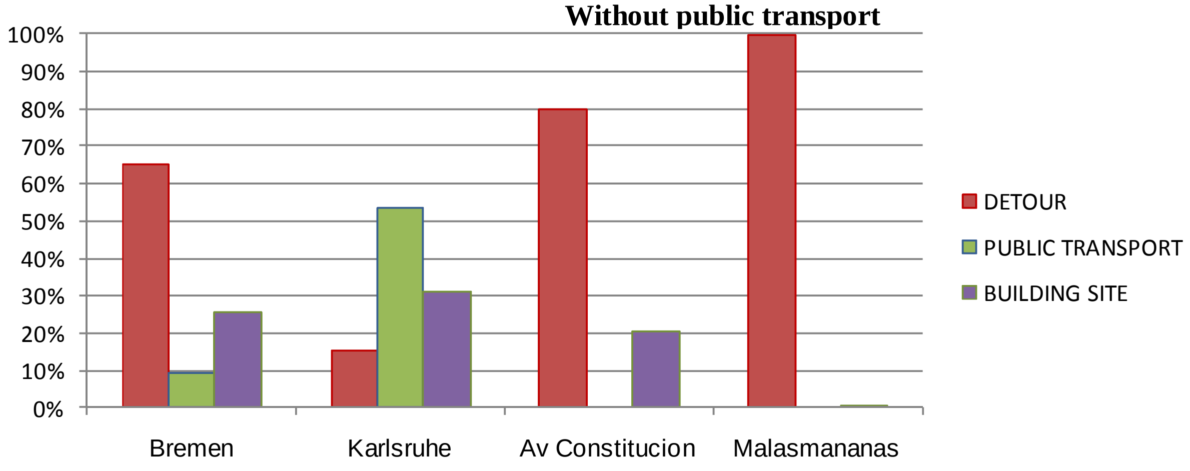
Figure 6

Comparison of Socio-Economic Costs and Life-Cycle Costs

At a first glance, we can conclude that the share of the socio-economic costs for the newly developed systems is lower than for the reference cases, which means a gain. A very important factor for the lower socio-economic costs is the reduction of time, which has an immediate effect on the different impact categories. As time is a multiplier in each formula, reduction of time means a reduction of costs.

If we look at the height of the socio-economic costs compared to the LCC, there are remarkable differences. For Bremen and the two cases in Spain (Malasmañas and Avenida de la Constitución) the socio-economic costs are between 5 and 10% of the estimated life cycle costs whereas the estimated socio-economic costs for Karlsruhe are much higher: around 50% of the life-cycle costs. This can be explained by the fact that the test site in Karlsruhe was in an urban area with a very high frequency of public transport, but also a reasonable amount of car traffic and a lot of neighbouring functions.

Figure 7 shows two graphs with the share of each impact category on the total costs. The first graph reflects the situation of the test cases, without a current public transport service in the Spanish cases. The second graph also takes a possible public transport service into account, which would be the case of renewal of the tracks in the Spanish test cases. We assumed that there will be replacement buses during the works driving the same length as the detour for cars.



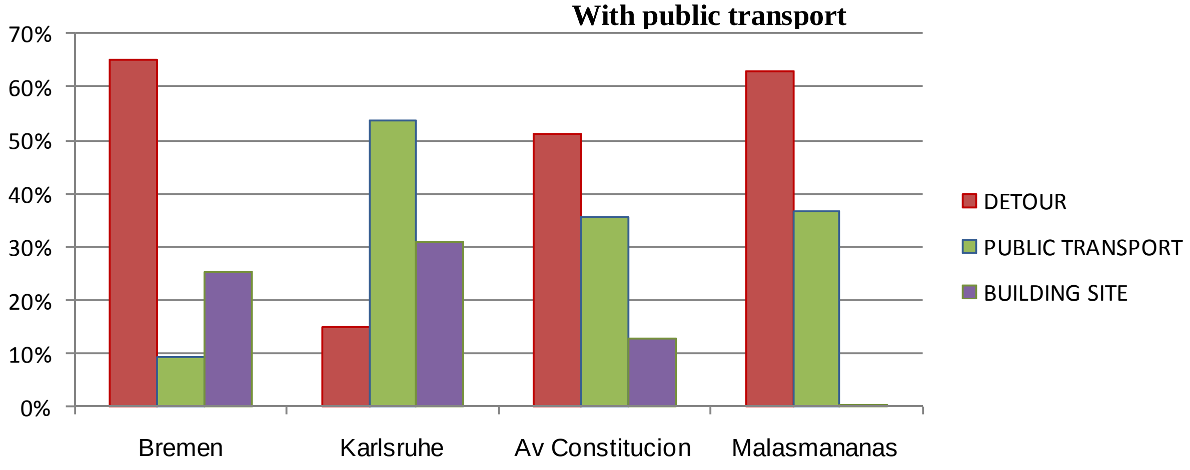


Figure 7

Share of impact categories on total socio-economic costs for test cases

If we look at the contribution of the different impact categories on the total socio-economic costs, we see that public transport is an important socio-economic cost in Karlsruhe and in the Spanish cases with public transport but less in Bremen, where it was possible to make a detour with the trams. The high share of public transport in the total costs for Karlsruhe is due to the very high service level of public transport with around 46 vehicles per hour. The results of the test cases also show that if there is a dense network of public transport available, the socio-economic impact due to public transport can be reduced by offering alternative public transport within walking distance and by using alternative lines instead of replacement busses.

Detour for car traffic is the highest socio-economic cost category in all cases except Karlsruhe. This has partly to do with the fact that the location in Karlsruhe was a more important axis for public transport than for car traffic. In general, we can say that in situations with a high amount of car traffic the most important socio-economic gain can be made by a short closure of the road.

The share of turnover on the total socio-economic costs depends very much on the amount of neighbours and businesses along the construction site. For businesses, it is also relevant how much of the area around the building site has a bad accessibility due to the works. Building sites with a good accessibility and minimum of hindrance result in lower socio-economic costs due the works. In the monetary calculations, the impact of time on turnover is the same as on the impact categories as it is a linear function. However, it is known that works that last long, i.e. months or even years have a more severe impact on those businesses than works just taking a few weeks. This element has been taken into account in the overall evaluation.

The main costs or gains during operation are caused by the noise level during operation and the maintenance costs. The socio-economic costs for maintenance are similar to those for construction works as they consist of the same impacts. The estimated gain due to less noise is directly related to the amount of neighbours and businesses within the impact area of the noise. In the model, we used one level for the reduction of noise for the whole life cycle although it would be more realistic to calculate with an increasing noise level over the years, related to the relevant maintenance sequences.

A fast installation time and expected long term quality of the system are advantages that are especially interesting in areas with a lot of businesses, a high traffic volume and a heavily used public transport: the shorter the disturbance, the lower the socio-economic costs. From the examples within Urban Track we can learn that it might be worth to consider a track system that can be installed and renewed very fast if it avoids hindrance. A prefab system can be combined with cheaper standard systems on less crucial stretches of the track. As the maintenance regime will be based on the most frequent used system, those advantages will be minimal, but the lower installation time and possible easier renewal might be worth the extra investment.

Another interesting aspect is the possibility to include advantages of a controlled fabrication process, which has mainly an impact on the long term. It is expected that the quality of the surface remains better on the longer term. The fact that noise reduction measures like rubber jackets around the rails are incorporated in the design of the module lead to a lower risk of mistakes during installation and thus to a lower risk on noise during operation. If just a LCC calculation is used, this type of advantages cannot be taken into account. Considering the socio-economic effects gives a more complete overview of the different implications of the methodology in which price at the moment of decision making is not the only factor to base the decision on. The methodology has been developed and tested in different validation sites, but should be further developed in order to increase the reliability and the comparability of the outcomes.

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ATTEMPT TO DEFINE A FUNCTIONAL AND STANDARDISED APPROACH TO URBAN TRACKFORMS

Functional and Standardised Approach

A functional approach of the track design means that the requirements are based on performance.

The interest and objectives of such an approach is to go through an optimisation process, which results in highlighting that several components can meet the requirements. And consequently increase the supply offer.

The performance can be defined in:

- Standards;
- Technical requirements;
- Local rules and regulations.

Currently the standards that are used in urban railway are mainly coming from mainline railway. The need to develop urban specific standards has become more and more urgent.

As a contribution to this, Urban Track was asked to work, within the sub-project 5, on the interest of application of existing railway standards and possible add-ons for urban rail:

> These recommendations will be made available to UITP for further elaboration and decision in line with EC initiative to deliver a programming mandate to CEN aiming at developing appropriate standards for rail systems which are excluded from the scope of the Interoperability directive 2008/57/EC by application of article 1.(3).

The whole list of EN track standards was reviewed and the applicability of each standard was assessed.

Some site surveys were carried out followed by dynamic simulations which results can be added to this contribution.

Applicability of Railway Standards to Urban Railway

The whole EN railway standards were listed in an excel file. Each track standards was examined and assessed regarding its scope of application (Light Rail or Metro) and its applicability to urban railway.

An extract of this list is shown below.

Matrix check (CEN) standards for urban rail

European	version	Title (EN) The words 'Railway applications - ' before standards titles have been omitted	national	scope: urban rail only	scope: heavy rail only?	LRT directly, without problems?	LRT with adaptations applicable	MRT directly, without problems?	MRT with adaptations applicable	not adapted for urban rail: why? e.g. operational conditions	not adapted for urban rail: additional items necessary (wish list)	standard non-applicable
EN 13149-5	2004	Public transport - Road vehicle scheduling and control systems - Part 5: CANopen cabling specifications		x							This applies to equipment installed onboard buses, trolley buses and tramways only as part of a bus fleet operation. It excludes tramways when they are operated as part of a train, subway or metro operation	
EN 13230-1	2009	Track; Concrete sleepers and bearers - Part 1: General requirements					X		X	No information for sleeper & contrete slab		
EN 13230-2	2009	Track; Concrete sleepers and bearers - Part 2: Prestressed monoblock sleepers					X		X			
EN 13230-3	2009	Track; Concrete sleepers and bearers - Part 3: Twinblock reinforced sleepers					X		X			
EN 13230-4	2009	Track; Concrete sleepers and bearers - Part 4: Prestressed bearers for switches and crossings					X		X			
EN 13230-5	2009	Track; Concrete sleepers and bearers - Part 5: Special elements					X		X			
EN 13231-1	2006	Track - Acceptance of works - Part 1: Works on ballasted track - Plain line					X		X		track tolerances for concrete and speed lower than 80km/h	
EN 13231-2	2006	Track - Acceptance of works - Part 2: Works on ballasted track - Switches and crossings					X		X		track tolerances for concrete and speed lower than 80km/h	
EN 13231-3	2006	Track - Acceptance of works - Part 3: Acceptance of rail grinding, milling and planing work in track					X		X		No information for grooved rail	
EN 13232-1	2003	Track - Switches and Crossings - Part 1: Definitions							x?			
EN 13232-2	2003	Track - Switches and crossings - Part 2: Requirements for geometric design							x?			
EN 13232-3	2003	Track - Switches and crossings - Part 3: Requirements for wheel/rail interaction							x?			
EN 13232-4	2005	Track - Switches and crossings - Part 4: Actuation, locking and detection							x?			
EN 13232-5	2005	Track - Switches and crossings - Part 5: Switches							x?			
EN 13232-6	2005	Track - Switches and crossings - Part 6: Fixed common and obtuse crossings							x?			
EN 13232-7	2006	Track - Switches and crossings - Part 7: Crossings with moveable parts							x?			
EN 13232-8	2007	Track - Switches and crossings - Part 8: Expansion devices							x?			
EN 13232-9	2006	Track - Switches and crossings - Part 9: Layouts							x?			
EN 13250	2000 +A1:2005	Geotextiles and geotextile-related products - Required characteristics for use in the construction of railways										

Figure 1 Abstract of Railway Standards List

Some examples resulting from that study are detailed below.

- Low stiffness fastening systems are often used in urban railway for vibration mitigations for example:
  - A global low range exists (Kdyn < 50 MN/m).
  - But very low stiffness are not separately dealt with.
  - What happens for instance with a stiffness of 15 MN/m.
  - Only one fatigue test configuration is defined which seems optimistic considering the various rolling stocks, and the different loadings undergone by the track.
  - No grooved rail reference to carry out the fatigue test.
- Rail welding (aluminothermic /flash-butt):
  - Nothing for grooved rail.
  - Nothing for urban load.
- Some characteristics of non-sleepered track cannot clearly be tested:
  - Embedded Rail (continuously supported): What length of rail coupon for fatigue test?
  - Anchored track (direct fastening): For both, no equivalent of sleeper standard.
  - Actually, a validation test of the track section should be subject to standardisation.
- Track quality:
  - Geometrical tolerances: lot of variation between Networks.
  - Tight tolerances are not economic as they increase construction and maintenance cost.
  - Loose tolerances: not economic either as maintenance appears too late and comfort criteria not met.
  - A statistical analysis to define track quality on a given length is to be developed as it is the case on mainline.
- There is no standard related to Corrugation:
  - Then the REX from Networks indicates it is a recurrent issue.
  - Nevertheless, the networks do not receive any recommendations.

- Track Maintenance – Restoration of rail:
  - Only applicable for Vignole > 49 kg/m.
  - Only applicable for plain line.
  - Difference in defect types.
  - Conclusion: a modification is necessary.
- Track Maintenance – Measurement of rail roughness:
  - Smaller running band in light rail.
  - Conclusion: applicable with modification.

The pie chart below summarises this study in figures.

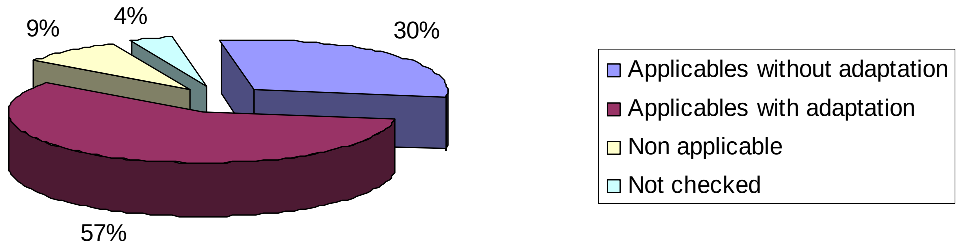

Figure 2

Statistics on applicability of EN Standards

Madrid Survey

A geometrical and vibration measurements campaign was done in Madrid in May 2010 on ML3 line.

A schematic of the line is shown below.

Figure 3

Schematic of ML3 - Madrid

This line was opened on July 27th 2007. The tramway operated on it is an ALSTOM CITADIS 302. There are 15 stops over a length of 13,7 km. The track form is a CDM Embedded Rail.
The track geometry measurement was done using a trolley, which is doing continuous measurement (every 25 cm) at a speed of 7 km/h.

Track irregularities surveys are relative.

Figure 4
Track geometry measurement trolley

The roughness was measured in the middle of the running band according to ISO 3095 using a CAT trolley.
The analysis was done with respect to: ISO 3095 and EN 13231-3 – grinding works reception.

Figure 5
Track roughness measurement - CAT trolley

Validation Tests of Standard Approach Criteria for Tramways

The measurement in Madrid were analysed and correlated with measurements made on other sites.

The analysis was carried out according to a reference based on the following principle design criteria:

- Track geometry;
- Track roughness;
- Groundborne noise and vibration performance.

Track geometry

The proposed reference is the EN 13231-1.

Measurements and simulations have been performed on several sites to correlate:
- Track geometry including tolerances;
- Accelerations (comfort) in tram.

These measurements and simulations demonstrate that:

- EN 13231-1 is applicable to non-ballasted tracks:
  - For directly fixed or sleepered track and continuously supported rail;
- Standard deviation approach is relevant:
  - A compliance of 95% is obtained;
  - An additional index will be proposed to cover 100% of the track geometry quality assessment;
- Comfort levels are satisfactory with this reference.

Track roughness

The track roughness on Madrid network is particularly good in comparison with other networks. The reason for this good track roughness can be related to:

- Madrid segregated track network;
- Grinding performed from March to November 2008;
- Continuously supported rails;
- Low traffic.

It is difficult to draw a conclusion for the moment.

Groundborne noise and vibration performance

The vibration performance of transportation system must be defined in relation to its compliance with a level of vibration measured at building locations but not empirical rules based on outdated data.

Measurements have been made on many sites to correlate simulations with measurements and for several tram designs and manufacturers as the vibration mitigation of track must be adapted to the vehicle that will be operated.

Conclusions:

- The whole vibration transmission path has to be considered;
- Very high performance (floating slab) are rarely required;
- Classic Direct Fixed Track, sleepered track (1 elastic pad) or Continuously supported rails are sufficient in many cases.

Rules on the Alignment of Light Rail Systems

The major objective of this work was to optimise the route alignment respecting:

- Safety;
- Speed (operation performance);
- Vehicle dynamics and ride comfort;
- Economic efficiency of the structure and operation including the maintenance.

Two approaches were followed:

- One numerical:
  - o Based on railway dynamics simulations;
  - o Taking account of impact in rolling stock.
- One analytical:
  - o Based on application of analytical formulae.

Conclusions

The following schematic give an overview of the work done.

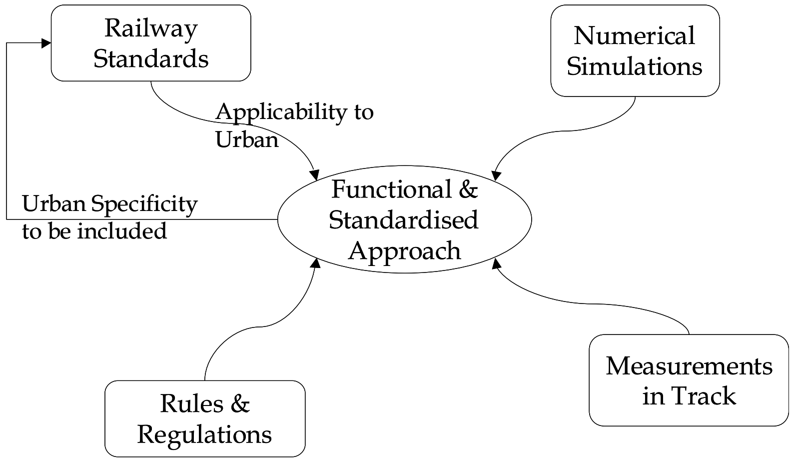

Figure 6

Standards specific to urban railway need to be developed at least for:

- Track alignment;
- Fastening systems;
- Maintenance;
- Noise & Vibrations.

Most urban standards can derive from railway EN (e.g. EN13231 is applicable with adaptation for defining acceptable tolerances).

ADVANCED MAINTENANCE OR HOW EXPERIENCES FROM MAINTENANCE NEED TO BE TAKEN INTO ACCOUNT FOR NEW TRACK SECTIONS AND NEW SYSTEMS

Objectives

The introduction of essential maintenance aspects in the design/construction phase is quite new for European tramway networks. In the past, only few calls for tenders for construction of tram infrastructure included a thorough chapter of future maintenance of the new tram infrastructure. More often than not maintenance aspects are neglected during these important phases of design and construction. However, this is a necessary step that should be applied by European track networks in order to avoid unnecessary higher maintenance costs due to insufficient design or poor construction materials or methods.

We have studied the organisational aspects of track management and particularly the link between design/construction and operations/maintenance. The final objective of this work was to present a list of recommendation and of best practice examples in relationship to the way the maintenance department within an urban transport operator or separate maintenance company is handling its resources.

The following questions were addressed:

- What are the key maintenance questions that need to be addressed before construction?
- How can the renewal of different track elements be optimised?
- What are the best communication channels between the construction and the maintenance department that will considerably improve track maintenance?

Methodology

In order to answer the questions defined above, this work was composed of two main chapters:

- Regulatory framework of tramway infrastructure construction and maintenance;
- Survey of selected European tram/LRT operators.

The first chapter introduced the European and national institutions in charge of implementing the directives and the regulations for tramway infrastructure. The second chapter the results of several surveys carried out with selected tram/LRT operators.

Regulatory framework of tramway infrastructure construction and maintenance

This chapter aims at presenting the general European and national legal framework for the construction and maintenance of tramway infrastructure today.

It is composed of the following sections:

- an analysis of ***European regulation*** and directives today regarding tramway infrastructure construction and maintenance,

– an analysis of ***National regulation*** regarding tramway infrastructure construction and maintenance and
– the specifications in calls for tender for the construction of tramway infrastructure.

European institutions and actors responsible for implementing the directives and regulations for tramway infrastructure

There are several European institutions in charge of organizing the railway system at a European or transnational level. These European institutions and instances play a major role in definition of the standards of European railways at a large sphere.

At a local level (urban), however, there are no European institutions directly accountable for the regulation and inspection for **urban tramway infrastructure**.

The European Railway Agency and European Metropolitan Transport Authorities are the most important European institutions playing an active role in the definition of European standards, which in some cases, can be applied to the urban tram networks in Europe.

The ***European Railway Agency*** is mainly responsible for regulating international rail transport. The main goal of this Institution is to support the establishment of a European integrated rail network by setting standards. Its main task is to develop economically viable common technical standards and approaches to railway safety. This agency works closely with railway sector stakeholders, national authorities and other concerned parties, as well as with the European institutions.

In some cases, these standards can be used by other modes of rail transport, including urban, suburban and regional networks. However, they are mainly destined to national and transnational networks.

In order to promote the standards, the ERA offers support to national bodies and conducts maintenance workshops, which promote the establishment of collective technical and regulatory prescriptions of maintenance procedures. These prescriptions are used, for instance, by the ***Trans-European Transport Network – TEN-T***. The management of this Program is responsibility of the ***Trans-European Transport Network Executive Agency (TEN-T EA),*** which administers the technical and financial implementation of all TEN-T projects.

A second objective of the ERA is the reduction of maintenance costs and the founding of standard quality certifications in all Europe.

Indirectly another instance worth mentioning is the ***European Metropolitan Transport Authorities (EMTA). EMTA*** is a meeting place for the public transport authorities from European Cities. The goal of EMTA is to enable the exchange of information and best practices between the responsibles for planning and financing of public transport services in the cities. It emphasizes the technical and multimodal approach, including transport policies and integration of urban transport systems. Through its studies, which are the subject of common interest of its members, EMTA proposes recommendations and takes initiatives with regard to European and international institutions.

European regulations and directives

Most of the legislation issued by the European Union aims at the definition of European public services contracts and the granting of European public aid regarding rail infrastructure at a European level. In some cases, certain legislation can be applied to local rail networks (at an urban or suburban level).

The definition of standards at a European level focuses on trans-national lines (both conventional and high-speed lines). The legislation presently in force is presented in Table 1.

Table 01: Legislation in Force in Europe		
Subject	Name and Type	Scope
Rail infrastructure: multi-annual contracts	Act of 6 February 2008 "Multi-annual contracts for rail infrastructure quality"	General
Allocation of railway infrastructure capacity and charging for the use of infrastructure	Directive 2001/14/EC of 26 February 2001	Domestic and/or international rail services
Interoperability of the trans-European rail system	Directive 2004/50/EC of 29 April 2004	Trans-European Rail Systems
Licensing of railway undertakings	Directive 2004/49/EC of 29 April 2004	General
State aid for railway undertakings	Regulation (EC) No 1370/2007 of 23 October 2007	General
	Community guidelines on State aid for railway undertakings of 22 July 2008	General
Railway Safety	Certification of Maintenance Workshops	Domestic or international rail services

Table 3 European Legislation in force regarding European rail systems

National regulation and recommendations regarding the construction and maintenance of tramway infrastructure

The regulations regarding urban railway infrastructure construction and maintenance at a national level of six countries were studied. The selected countries were Germany, Austria, Switzerland, Norway, England and Spain.

In general, the following can be said regarding all national rail legislations analysed:

- Each country has its own specific regulation regarding tramway infrastructure,
- Opposed to railway vehicle maintenance, which urges a certain certification, there is no certification required for tramway infrastructure maintenance.

Calls for tender for construction/maintenance of tram infrastructure in Europe

There is little bibliography today referring to maintenance aspects in tender documents for European track construction. This is because for the most part, maintenance is only taken into account after track construction.

There is however, a great number of articles that deal with overall vehicle and track maintenance, best practices in case of partial or total track renewal, and recommendations for the preparation of light rail vehicle tender documents.

The introduction of maintenance care in an early phase such as design and construction is quite new for European transport networks. Usually calls for tender in Europe are prepared and presented for the various activities concerning tram infrastructure: design and/or construction, infrastructure maintenance and operations. A maintenance chapter is usually not included in the calls for tender for the construction of new tramlines. However, there is growing attention for this subject. After the discussions with the different European operators, we see that some of the transport authorities or operators interviewed see the need to integrate such a chapter in future calls for tender for new tram infrastructure construction.

Interviews carried out with European tram operators

Within the research project of Urban Track, a number of interviews were carried out with several European tramway operators. These surveys concerned only light rail urban tracks. Other types of tracks (subway, tramway-train tracks, and tracks for regional trains…) were excluded.

When selecting the operators for this survey, two main aspects were taken into consideration: the age of the network (which plays an important role in maintenance regimes) and the type of infrastructure management.

Figure 1

Selected cities for the survey

The objective was to analyze a sample of tram network organisational structures as diverse as possible. The purpose was to identify the general maintenance problems observed in all networks and analyze problems associated with a specific tram management scheme.

In reality, there are more than three tram management schemes. However, in order to simplify the classification, we have chosen the three management schemes with the greatest differences:

- All-in-the house operation,
- Semi-segregation of operations,
- Complete segregation of operations.

Types of management schemes

All-in-the house operation (Publicly owned networks)

Generally, publicly owned networks carry out all their activities of construction, renewal, operations and maintenance in house and only sub-contract marginal activities.

The transport company is responsible for the management of the overall urban transport service. It has therefore complete control and direction of all these activities.

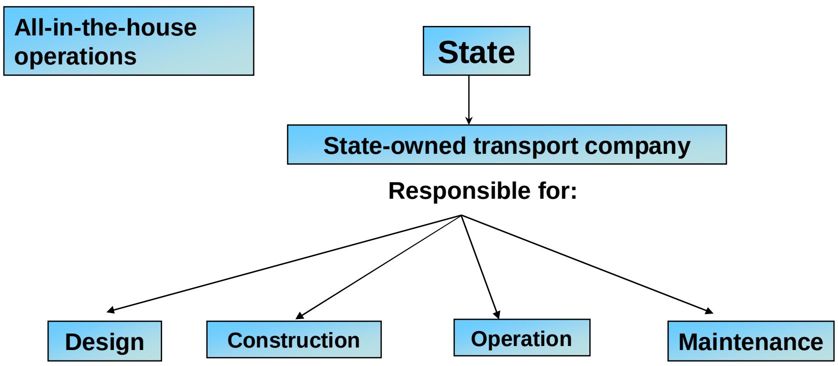

Figure 2
Organisational scheme of publicly owned tram networks

Semi-segregation of operations

In tram schemes with a semi-segregation of activities, the principal activities of construction, operations and maintenance are carried out by at least two different companies. The Transport Authority awards several contracts in parallel, but at a minimum two: one with the transport company (with duration of 5, 10, and 20 years depending on the country's legislation), and one with the construction consortium and/or the maintenance contractor (infrastructure/vehicle).

The Transport Authorities must deal with different contracting companies and must assure overall control, coordination and overview.

The illustrations below present two examples of semi-segregated schemes. The first one shows a classical division between of the activities of design/construction being carried out by a specific consortium and operation/maintenance being carried out by another.

The second diagram shows the carrying out of maintenance by two different companies (the operator being in charge of overall maintenance and sub-contracts some of the maintenance activities).

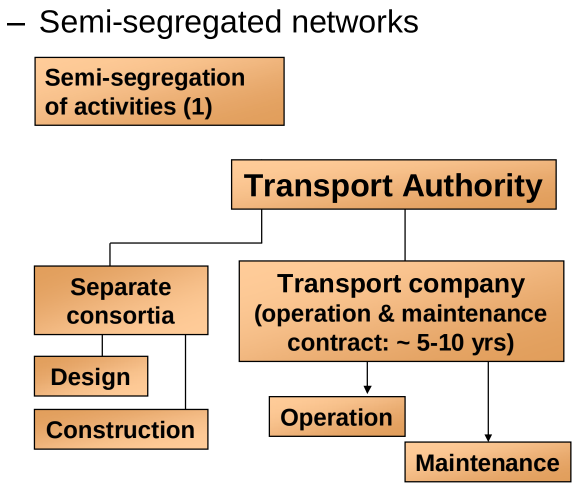

Figure 3

Organisational scheme of semi-segregated tram network (1)

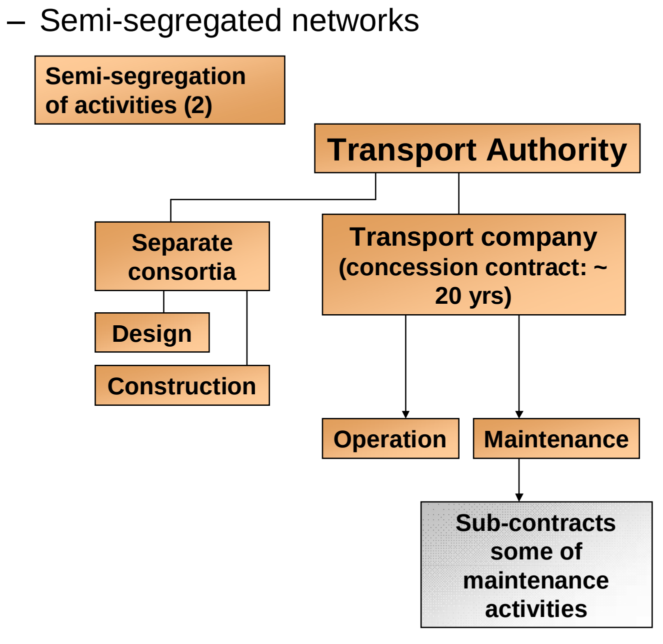

Figure 4

Organisational scheme of semi-segregated tram network (2)

Complete Segregated networks

In this last scheme of tram management, all activities are completely separated.

In this specific scheme of organization and in comparison to a scheme of semi-segregation, the Transport Authorities have even more responsibilities of control and coordination of all involved contracted companies since they pass contracts with each of the different company separately.

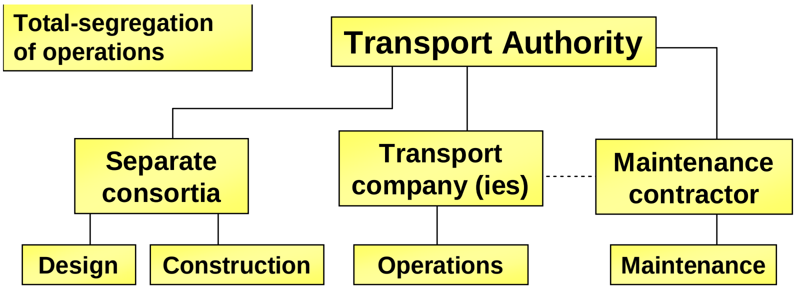

Figure 5 Organisational scheme of segregated tram network

Classification of selected tram network operators according to its type of organisational scheme

The sample chosen constitutes of:

- three ***state-owned networks*** (all-in-house activities):
  - Karlsruhe's tram network (since late 1800s);
  - Prague's tram network;
  - Flemish tram network (De Lijn).
- four networks where the main activities of design, construction, operation and maintenance are ***semi-segregated*** (i.e. one transport authority and one public transport company in charge of at least two of the main operations: operation and maintenance, or of all main operations: construction-operation-maintenance):
  - Strasbourg's tram network (different construction years of the different tram lines, construction of the first line in 1994);
  - London's Croydon Tramlink tram (since 2000);
  - Paris' tram network (different construction years of the different tram lines, construction of the first line in 1992);
  - Lyon's tram network (construction of T1 in 2001).
- three networks characterized by having ***complete segregation*** of main activities (one transport authority, several construction design and construction consortia, one or several operators and one or several maintenance contractor).
  - Seville's tram line (construction of a section of the first tram line: 2007);
  - Dublin's LUAS tram lines (construction of the red and green lines: 2004);
  - Barcelona's tram network (construction of T4 and T5 between 2004 and 2005).

Advantages and disadvantages regarding different track management schemes

Maintenance management has major impacts on all aspects and at all stages in the life cycle of a light rail project. It affects design and contract policy, capital and operating costs, reliability and quality of the service. In general, it can be stated that:

- It is important to decide the overall maintenance strategy and work policy as early as possible, e.g. work to be done wholly or partly in-house by the Promoter/Client or Contractor for the different parts of the system: vehicles, fixed equipment, track, structures and buildings.

- This decision affects both the type of the contract, e.g. Life Cycle Cost (LCC), and the size of the Promoter's organisation, staffing and accommodation.

Overall, it can be stated that the three different organisational schemes (all in the house, semi segregation of operations and complete segregation of operations) have a significant impact on the overall public costs of the service (construction + operation + maintenance).

For each scheme of track management, different human, technical and financial resources are required. Each scheme has its advantages and disadvantages in terms of public costs, level of transparency and of implication and control of the transport authority. A great task for new transport authorities is ***to determine which scheme it is the most adapted to its needs and to its resources***; for transport authorities the two main question to be asked is what kind of changes are necessary in our current structure to reduce costs and ensure a certain standard of public service.

When comparing the two most contrasting organisational schemes (complete segregation vs. in-house organization), the following can be said:

- **Regarding overall costs**, due to synergies within the same organization, an all-in-house organization could present lower overall costs (due to synergy effects within the same structure) than a completely segregated organization, which requires a higher number of interfaces between the various contracting companies and therefore faces higher overall costs (costs of administration, coordination and control of all contracts awarded ...). The complete segregation is normally associated with the theory that with a strong private sector involvement, the cost will be generally lower when compared to a pure public body. This might be partially true, but the additional cost to manage interfaces is cannibalising these cost savings and in total, the overall picture (always assuming a similar level of transport quality) is often not in favour of the segregated solution.
- **Regarding the level of transparency**: A down side of an in-house organization is that many procedures are done internally and could not necessarily be presented publicly. However, when an in-house organization is well structured, this organization has the potential advantage of reacting faster and "having things done" faster than in complete segregation, since many important activities are done internally and are not necessarily put out for bid.
- As for a completely segregated organization, we can identify a certain level of transparency because every single call for tenders must be made publicly (regarding design, construction, operation and maintenance of tram infrastructure and vehicles). However, longer and more administrative procedures are usually linked to this type of organization, which also mean longer periods before intervention.
- A crucial factor is the **level of implication and responsibility of the contracting authority** according to the different types of organization. In this work package, all in-house organizations studied are 100% publicly owned. In these cases, the operator assumes overall control and co-ordination of the most important track activities. It decides which activities to externalise but it keeps control of these activities at all times (examples: Karlsruhe, Prague and De Lijn). In these cases, the contracting authorities (cities, provinces or governments) decide on all new public transport projects and extensions. Once new projects are decided within this level, the operator assures all the control and

the coordination. The contracting authority "decides" and the operator "co-ordinates and controls locally".

In a completely segregated organization, the transport authority must decide, but also co-ordinate and control all the different contracts with the respective companies or with the consortium in charge of construction, operations and maintenance. The interests of all parties involved often do not go in the same direction, which is an inherent problem. In order to succeed within this organization, the authority must have sufficient resources in order to carry successfully out these three important tasks. In some cases, the last two (coordination and control of all contracts) are somewhat neglected and this is reflected in the transport service itself.

Regardless of the organizational system, the contracting authority should have at all times significant information regarding all current contracts (construction, operation and maintenance) in order to intervene in case it is necessary. This is one of the major problems identified today; many contracting authorities loose control of their systems because they do not posses the most significant information regarding the different contracts. Once an activity has been "put out", many authorities believe that many aspects related to the specific contracts do not concern them anymore. It is perhaps the other way around. Authorities that decide to put out certain activities must have enough human and technical resources to coordinate and control the different contracts adequately and fix long-term strategies regarding operations and maintenance.

It is therefore very important for the public transport-decision makers to find the scheme matching their demands and their capacity of management.

Lessons learned

Lesson n°1: do not underestimate the power of a tool for internal maintenance knowledge

Throughout this research, we have noticed the fact that in many networks, the real knowledge of the tracks' conditions is being held by a reduced number of personnel (track conditions and development). When this personnel leaves the network (retirement, change of work), this "precious knowledge" leaves with them, because the network does not have a tool of knowledge of maintenance. Therefore, it is very important to register in specific software the tracks' history, its aging and its development.

Lesson n°2: it is very important to keep good channels of communication between the maintenance and the construction departments in order to minimise general LCC costs

The closer the relationship between the maintenance and the construction departments, the better it is for implementing accurate maintenance plans and for producing more efficient track designs and to make improvements to the system. Throughout the interviews carried out, we have noticed that in the cases where this link was strong, the results in terms of maintenance cost reductions were significant.

Lesson n°3: organisational schemes produce different overall public costs (construction + operation + maintenance)

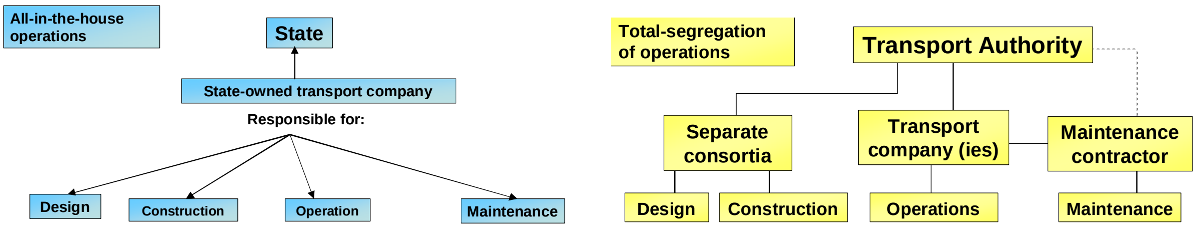

Figure 6

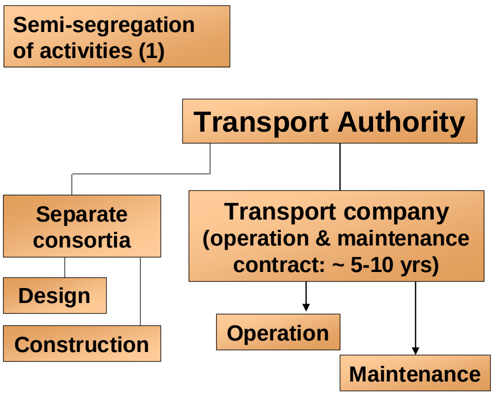

Figure 7

The way of conceiving public transport services VARIES CONSIDERABLY according to the organisational scheme chosen. For each scheme, different human, technical and financial resources are required. Each scheme has its advantages and disadvantages and this should be taken into account when organising urban rail bound public transport schemes.

Lesson n°4: regardless of the track management scheme, the contracting authority should assume at all times the role of coordinator and must fix strategies of maintenance and operations.

The contracting authority should, at all times, have enough information regarding all current contracts (construction, operation and maintenance) in order to manage the different contracts and must have always full control over the important assets and procedures (from the procurement to the operation contract). "Putting out an activity" does not necessarily mean less work for the contracting authority. It means finding ways of keeping a balance in the control of the different contracts (keep in control of general strategies) and the necessary amount of resources of personnel needed for this.