Project no. TIP5-CT-2006-031415

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D 2.3.1 Validation methodology and criteria for the evaluation of frame type, unballasted or slab-track based superstructure innovations

Due date of deliverable: March 2008

Actual submission date: 15th September 2008

Start date of project: 1 September 2006 Duration: 36 months

Organisation name of lead contractor for this deliverable: Corus

Revision f3

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of Contents

Executive Summary

INNOTRACK Sub Project 2 aims to investigate new track support concepts, which can improve on the effectiveness of conventional ballasted track to support railway traffic. A number of such concepts have been proposed and range from small changes to conventional systems through to slab – track and beyond using radical alternative designs incorporating novel materials. Development of innovative tools to optimise the design of these track forms are also being explored and techniques for adapting maintenance procedures to meet increasing traffic demands and reduced access times. WP2.3 focuses on the superstructure and on optimisation of its design and/or components on the basis of numerical simulations, laboratory experiments and full size tests.

In order to assess modifications to conventional ballasted track or to evaluate the effectiveness of the novel track forms studied, a clear definition of the requirements of the supporting superstructure must be established

The purpose of this deliverable is to provide quantifiable criteria that can be used to assess and compare the precise benefits of each potential solution. In this way the design and optimisation processes can proceed against a scientific background and any benefits of the novel solutions can de demonstrated and quantified.

As the effects of changes in the support structure can be wide reaching and can influence the performance of other parts of the system, the engineering criteria that make up this defined methodology are divided into the areas where these effects can be measured and quantified.

A common parameter to combine these competing criteria is that of cost. Optimisation for cost using universal rules is difficult – this has been the subject of other studies outside the project, which will be brought to bear if appropriate.

Notes: -

The text of this deliverable may be combined with the text of parallel work for WP 2.2

1. Introduction

Evaluation of new track structures in a research project will initially focus on the physics and mechanics of behaviour according to the engineers' normal design approach for dynamically loaded structures. Evaluation for the purpose of future beneficial exploitation requires a combined assessment of the safety, engineering, cost, environmental and operational issues. This first part of the deliverable lists the more evident parameters that would be expected for evaluation, discusses the scope of the infrastructure managers' requirements, and to what extent they are realisable within the research phase.

It is recognised that in a multi-parameter evaluation, there will be a desire to rationalise the comparison with previous track-forms through translation of each parameter into a cost. Approaches for doing this will be mentioned, using a commonly agreed cost coefficient for each parameter where these exist. In some cases the solutions will be specific to particular types of problem for which are there are no alternatives per se apart from track renewal at a greater frequency, the cost of which then provides the reference.

Notes

1) ***Use of relative improvement criteria for maintenance or upgrade***

   In addition to defining performance characteristics (or acceptable ranges within which performance measures should lie), it is appropriate to consider also the objectives of the use of a new track form solution, especially where the system is being installed in order to refurbish a line to bring its rate of deterioration back to acceptable levels with a given degree of investment. In this case the evaluation criteria may be specific to the type of solution. NB An important factor (raised in the review process) is the compatibility of new designs with existing solutions .

2) ***Slab-track problems***

   WP2.3 is dealing with variations on the theme of slab–track which has slab-specific "dynamic feedback" issues which can increase damage – irregular stiffness of the subsoil, bridges and tunnels under the track, differential settlements, cracks of concrete slab, degrading rail pad stiffness support in the vertical and lateral directions, transitions problems in the transfer to conventional track etc. An overall evaluation procedure should cover the susceptibility to these issues e.g. benefits of differing stiffness of track, and the ability to sustain good condition under different load and support conditions

3) ***Railway track problems***

   A further subset of inputs and outputs are the response to "problems" such as rail corrugation, tolerance to poor rail geometry at installation or repair, inadequate joints, vulnerability to loads from "bad" rail vehicles, ease of maintenance or emergency repair etc.

4) ***Environmental impact***

   A principle concern of railways is the issue of noise and vibration on slab tracks. This must have a separate and properly dealt with evaluation, together with listing of possible amelioration methodologies where the particular design is used in a susceptible area.

2. Evaluation Criteria

2.1 Costs and Operations

2.1.1 Ease of construction and installation

This aspect includes the cost of construction and installation and also the cost associated with disruption of service.

The superstructure designs have a continuing driver of installation cost reduction, to meet Innotrack objectives and naturally to make the solutions viable. The ease of construction is particularly important here and will be illustrated by the inclusion of a breakdown of the works required. One particular benefit of some of the innovative solutions is to reduce the earthworks needed or pre-treatment of formation. To demonstrate this fully the validation methodology for cost comparison will require a typical installation project work-through, so that practical and calculated information is needed after the design stage to demonstrate the costs associated with given track system designs and the particular installation techniques used. The direct reporting units for this have to be such as to allow good relative comparisons whilst maintaining commercial propriety.

Reference for new build or straightforward renewal will be conventional ballasted track and the well-established existing slab-track solutions for main line / high-speed track new build.

For retrofit and problem solving solutions, a cost comparison should take into account the benefits and cost relative to either current methods or simply “the cost of the problem”. In this case it would be hoped to introduce a ranking of solutions for given track problems submitted by railways, which will be illustrated through case – history studies (also relevant to 2.2 combined activities)

2.1.2 Maintenance

The principal objective of the slab-track systems is notionally “zero-maintenance”. The actual maintenance requirements for the basic structure may indeed be reduced to “low probability high cost” incidents, however the design of the track may influence aspects of track maintenance from rail to signalling, so that a comprehensive review would be required. Individual components within the system may have a finite life, so that any inspection and replacement patterns would have to be crosschecked, with the consequence for life cycle costs noted.

2.1.3 Benefits of Innovative Design

An element of WP 2.3 is the inclusion of advanced forms of condition monitoring which will allow more sophisticated measurement and analysis of track. Where possible this and other benefits should be quantified.

2.2 Engineering and Safety

2.2.1 Background

The main role of the track is to support and guide the railway vehicle. The forces between the vehicle and the track are carried through the wheel-rail interface and include vertical support, lateral guidance acceleration and braking. The role of the supporting structure under the rails is to distribute these loads evenly and to continue to provide continuous support through track features such as curves, switches, gradients, changes in ground conditions etc.

If the support structure fails to provide this continuous support then the forces at the wheel rail interface will show greater peak values and this in turn will result in increased forces on the vehicle and on the track and substructure and on the sub components within these system, and on levels of noise and vibration. The effect of these forces may depend on a great many variables such as the amplitude, frequency and location of the support changes. In the following sections the key effects are catalogued and, where possible, available methods of quantifying these effects are summarised.

2.2.2 Effects on the rail

Rail wear

Wear on the rail head or gauge corner is a natural process when railway vehicles run but the rate of material removal can increase significantly if the forces and the contact conditions are not well controlled. This can cause particularly severe problems if the wear causes significant changes to the cross sectional profile resulting in a change of the running surface as seen by the wheel. Irregular surface wear can result in roughness or corrugation and a consequent increase in rolling noise.

Clearly non-continuous support from conventional track is a possible contributor to undesirable wear patterns, but in reality steady state wear itself is not expected to be a major criterion for evaluation of superstructure performance, with the presumption that the main objective of the design is to make the support as uniform as possible. By contrast wear which is enhanced due to dynamic effects is important and the designer does have to make sure such effects are eliminated as much as possible It would be left to a designer or supplier to establish a measure of improved performance here if he thinks it is relevant for the promotion of the product, but it is not a critical part of the research activity. There may be interest in specific examples such as in S&C or in curves, as a function of the values of lateral stiffness and contact patch location but in these instances more specific studies would be needed, as the usual models may not be applicable. Given that a specific effect of the superstructure innovations can be to improve lateral stiffness and permanence of geometry, it would be particularly relevant to assess the changed effect of lateral wear and wear patterns over time.

It will be particularly important to ensure that the specific wear related phenomenon of corrugation does not occur with the design, and a validation of this is important. [See section 2.3.1 Noise and Vibration.]

Rolling contact fatigue in rails

The impact of superstructure design on RCF is an important criterion which slab track has the potential to improve simply through the reduction of variability of the support, provided the designers avoid past problems of slabtrack for example inadequate resilience and changes of stiffness at the transition to or from ballasted track. From a track standpoint the principle controlling measures of rail support stiffness and dynamic receptance will be important parts of the designs. Following optimisation, a slab track or innovative sleeper system will wish to claim benefits for RCF and models may be used to rank the behaviour compared to less controllable designs, e.g. conventional ballasted track. (This is an activity being undertaken jointly with SP1 and SP2)

Rolling contact fatigue (RCF) occurs if the rail surface is subjected to repeated plastic deformation as often cause by repeated wheel passages. If the forces generated are below the shakedown limit for the material it is possible for them to be accommodated through elastic deformation and RCF avoided or delayed. The dividing line between these cases is not easy to establish but the factors influencing the generation of RCF are the normal and tangential forces at the wheel-rail contact and also the contact conditions (mainly the prevailing coefficient of friction). Some tools have been proving effective at predicting whether RCF cracks will appear for example the shakedown curve weighted TGamma curve currently being used by Network rail. More sophisticated models are available which allow comparisons including metallurgical parameters which may be more useful for the broader application of the results across different networks. The costs of rail RCF are mainly associated with its prevention (through inspection and grinding or replacement).The calculation of benefit will consist of understanding what part of cost of rail RCF is attributable to uniformity of support and specific ranges of stiffness of support – then saying this reduces to virtually zero, in the case of monolithic slabtracks. For basic formation improvement scenarios, RCF will not be a primary measure.

Rail stresses

The stresses caused to the rail body further away from the wheel-rail contact are much lower than the contact stresses themselves but they can also result in fatigue in other parts of the rail. Fatigue cracks can result in early removal of the rail. Reduction of rail stresses is a potential direct benefit of some forms of rail support associated with slab track.

Tools are available for predicting the development of fatigue within a loaded rail, from which it will be possible to estimate the statistical reduction in rail breaks and their consequent costs. The direct costs associated with rail fatigue are inspection and early replacement of rails.

2.2.3 Effects on the formation

The bearing stresses acting on the formation are affected by the design of the superstructure, particularly the area over which the static and dynamic loads are distributed. Uneven forces cause differential settlement and some techniques have been developed to estimate this based on the predicted forces and their location.

The superstructure options may range from flexible combined solutions for very local problems through to major main line investments. The criteria for evaluation of a new track system will depend on its objective e.g. is it to

a. Be of global application for fit and forget,

b. Solve specific formation problems,

c. Give a “zero maintenance track” if put down with / without special formation treatments/sub-layers.

d. Each of these for S&C only.

To “prove” acceptable behaviour for the particular application, designers need to compare predicted stresses with specifications of failure criteria for different sub-grade materials –those in existing tracks or those to be specially prepared when the construction is on new formation.

Whilst a global and recognised criterion is periodic track quality degradation due to vertical settlement rate, this can be a result of different types of degradation e.g. erosion and rate of fines generation or in the case of clay containing soils, exceeding the bearing capacity. A basic problem is that with intermediate forms of slab track the degradation behaviour might be different because, to give two examples,

a) particles from degrading ballast have been part of the formation degradation process in conventional tracks,

b) drainage arrangements and behaviour are likely to be different

and

c) pressure distributions are likely to be quite different.

This means that reference data may not be easily available. To make relative comparisons between a “reference” and various designs in WP2.3 models, initially it is proposed to use simpler parameters e.g. shear and normal stresses and strains, and for example the relative displacements compared with modelled behaviour of existing tracks, with recognition of differing soil types and conditions in the setting of threshold criteria.

Translation of these parameters into life and cost estimates for optimisation purposes will be difficult except where immediate sub grade is mostly artificial and predictable with a target of “zero” maintenance. For solutions which might be undertaken in conjunction with formation improvements from WP 2.2, then relative changes of behaviour will be useful even if they fall outside the criteria for an idealised new track performance. In-track behaviour (displacements/strains/ elastic wave response) will be required, but the criteria may be specific to the solution. The most direct measure before and after an installation from a track engineer’s point of view will be the measurement of degradation rate of the longitudinal level which is a good parameter to localize defects in the formation.

2.2.4 Effects on the vehicles

Potential derailment

The nearness to derailment is usually assessed by the ratio of the lateral to the vertical force at any wheel. A limit (often 1) is set to reflect the maximum limit beyond which the possibility of the flange climbing up the rail gauge face and the vehicle derailing increases rapidly.

It is difficult to provide a cost for this problem but it provides a limit, which must not be exceeded.

Passenger comfort

Methods have been established for assessing the effects of accelerations on human discomfort and these usually include a vehicle dynamics simulation with a frequency weighting applied to the predicted accelerations at the passenger location. These methods can provide a limiting exposure time for a particular vibration characteristic after which comfort level is reduced.

It is not anticipated that the innovative solutions will be particularly judged by their effect on passenger comfort, with a more likely requirement that this parameter should be “as good as or better than at present” on the best lines. The picture is different for remedial superstructures, in which the benefits may be, for example, to “iron out” undulations of ground stiffness, with consequent benefits for ride

The benefit to cost associated with improved passenger comfort may be loosely associated with greater passenger uptake and more directly with reduction in possible speed reductions due to poor ride on conventional track.

Wheel wear and RCF

Wear on the wheel is similar to that on the rail but as well as the rate of material removal the profile development is affected by the contact conditions and can result in hollow treads or thin flanges or in changed conicity and consequent poor vehicle behaviour. The level of wheel wear can be measured relatively easily using a miniprof device or similar. A number of effective tools are available for predicting wheel wear in a similar way to rail wear. *The cost of increased wheel wear is in the requirement for more frequent turning and reduced wheelset life with a possible measure the wear index using the Archard wear model.*

RCF occurs on the wheels as well as the rails and can result in surface damage, cracking and spalling. Similar tools can be used to predict wheel RCF based on the contact forces and conditions.

The costs of wheel RCF are mainly associated with its prevention (through inspection and re-profiling or replacement). As for rail wear, this is not expected to be a dominant criterion

2.2.5 Typical load cases to be considered for engineering evaluation

Philosophy

In order to assess any novel track form or modifications to conventional supporting structures it is necessary to define specific cases, which are ideally typical of the duty conditions that the track will face. It is also important, for the purposes of simplifying the evaluation to a manageable number of measurements or calculations, to limit the number of these cases as far as possible.

Example Support cases

The aim of these cases is to test the response of the support structure to a deviation from perfect supporting ground conditions. The cases suggested here are proposals but the exact values should be selected so that the cases are intended to be typical of the most severe variations found in real track (suitable measured data may become available from WP2.1).

Case 1: A reduction in the formation support stiffness below one rail for a short distance

Case 2: A cyclical variation in support stiffness for a longer distance

Example Vehicle cases

The aim of these cases is to provide representative vehicles, which will respond to the proposed superstructure's ability to accommodate the support cases.

Vehicle 1: A typical laden freight vehicle (e.g. Y25 suspension)

Vehicle 2: A typical main line locomotive and passenger rolling stock

2.3 Environmental Impact

2.3.1 Noise and Vibration

The environmental impact of noise and vibration from new track designs is an important part of the evaluation. Mechanisms and acceptable levels have been studied widely both in individual countries institutions and through EC research. The WP 2.3 objective is not to create new criteria, but to achieve similar levels of noise and vibration to existing conventional track, and where possible to improve on these. From a vibration and wheel force point of view this will typically lead to the rail support being significantly softer than for conventional track, with adverse consequences for rolling noise. The work of the project will be to design using recognised principles for reducing unwanted vibration (whilst ensuring appropriate receptance values as seen by the wheel to control contact forces). Noise and vibration levels will have to be predicted and there may be a need to introduce improvements for achieving suitable levels. In the final analysis the criteria can be stated as values of noise and vibration likely to occur with given traffic characteristics.

The validation methodology will include

1) Using an established comparative modelling method for ground vibration analysis that can be applied to different solutions mounted on different formations,
2) Model based noise prediction using periodic structure models and TWINS,
3) Direct measurement methods of noise and vibration on installations,
4) Specific evaluation of the propensity for corrugation growth using a roughness growth model as part of the design process.
5) In practical applications, measurements of the dynamic characteristics of the soils.

Whilst the acceptance criteria existing will be referred to, the research component will include commentary on the applicability of the newer modelling methods as part of the validation methodology.

At a practical level the criteria for evaluation should also raise the question of whether known methods for reducing noise can be applied (e.g. dampers, barriers) and what the cost element of this is to gain parity with conventional track noise levels.

Overall the evaluation will answer the question "does the design overcome the expected problems of noise and vibration in slab-track?"

2.3.2 Environmental life-cycle cost

Environmental life-cycle cost evaluation will be included as an option within the list of items for evaluation criteria.

3. Summary Table of Evaluation Criteria

General Categorisation Parameters
Type of construction: categorise according to slab / slab-type / enhanced sleeper type
Existence of Railway authorisation or allowance for operational testing;
Design or Authorised speed and traffic volume
Construction height:
Specific Categorisation Parameters
Types of track problem to which the solution is applicable
To be used in conjunction with special ground treatments only
For use with specific track types / S&C
Formation types and stiffness allowable with the design
General Life Cycle Cost Evaluation Criteria
Ease of construction and installation
Achievable accuracy of track alignment
Construction costs in € per linear track metre
Construction time
Maintenance requirements and costs
Type and frequency of inspections required;
Additional System Benefits of Innovative Design
Specific Engineering, Safety and Environmental Criteria
Predicted Track Quality behaviour with time
Tolerance of exceptional ground movement
Tolerance of non-standard loading conditions
Drainage arrangements and “Performance”
Ground Vibration Performance
Predicted Noise Performance
Possible Noise protection system
Effects on the vehicles (derailment potential, comfort, wheel wear and RCF)
Effects on the rail wear Rolling contact fatigue Rail stresses
Environmental Life-Cycle Cost

4. Conclusion

This deliverable has required a review of all the potential criteria for the evaluation of new track forms, with particular emphasis to the slab tracks being developed in WP 2.3. The principle outputs have been a listing of the significant areas and a commentary on their relative importance. In broad terms they can be divided into engineering, safety, operational and cost, and for all of these there are references of one kind or another, either being developed in the Work Packages of Innotrack or in existing standards. The deliverable attempts to highlight those criteria that can be most usefully employed to assess and compare the precise benefits of each potential solution.

The effect of the deliverable has been on two levels – first in guiding the design process for new slab track development in WP 2.3 (see deliverable D2.3.2) , and secondly in providing some of the subject areas where LCC analysis should focus.