Project no. TIP5-CT-2006-031415O

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D1.1.2 Database of European generic vehicle characteristics

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Revision 1

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Dissemination Level		
PU	Public	PU
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)	

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Executive Summary

Infrastructure Managers have traditionally been cautious regarding the introduction of new technology into the railway system, as unproven innovation may introduce unexpected and serious risks. Product acceptance procedures may further inhibit or prevent the adoption of new ideas as the benefits may be considered insufficient to justify the risks. The result of this caution is that some regard the railway as unreceptive to new ideas, and lagging behind other transport modes. InnoTrack should correct this view as the IMs seek to reduce whole life costs by the introduction of new technology. However the need to ensure that the innovative solutions resolve the issues and do not import new problems to the railway remains.

SP1 seeks to address this need within InnoTrack by modelling the vehicle track interaction for the problem conditions identified by the IMs to ensure that the root cause of the problem is fully understood and that the solution proposed successfully addresses this cause without introducing new risks.

The simulations must ensure that solutions are suitable for a wide range of present and future traffic conditions across Europe, focusing particularly on mixed traffic railways. Such a study has not previously been carried out on a European level.

The function of WP 1.1 is to gather the vehicle characteristic information to enable InnoTrack to ensure that most technical solutions are suitable for the wide range of vehicle characteristics possible in Europe not only now but also in the future.

As a first step deliverable D1.1.1, "Database of representative vehicle types and characteristics from participant countries", identified the representative vehicles and their characteristics for the European partners. A database of summary vehicle data was developed to enable the selection of representative European vehicles which would form the basis for generic vehicle models.

Although the amount of detailed vehicle information provided was limited, Manchester Metropolitan University (MMU) already has a range of vehicle dynamics models which not only represent UK vehicles but are also representative of a number of European vehicles. Data provided by Banverket (BV) has helped to identify with greater certainty a more complete range of detailed European vehicle characteristics.

This paper proposes that for each of seven European vehicle types, three models will be produced representing a low impact vehicle, a high impact vehicle and what may be considered as close to a typical vehicle.

MMU have already developed the generic model for the Multiple Unit case which can be used for the basis of the three Multiple Unit generic models.

Although the database includes some wheel and rail profiles, there continues to be an urgent need for partners to provide libraries of profiles for moderately worn and fully worn wheels and rails under a range of operational conditions. This is important as the forces generated by new wheels on new track are frequently very different to the interaction of worn profiles and it is essential to ensure that the range of conditions and load spectra that track is subjected to can be accurately characterised when verifying the solutions developed by the InnoTrack project.

1. Introduction

The correlation between vehicles and track forces which cause track degradation and failure rates must be established in order to evaluate the Life Cycle Cost benefit resulting from improvements in materials, design, construction and maintenance practices proposed within InnoTrack. SP1 has focused on identifying the critical problems encountered by participating IMs and is attempting to define the root causes of degradation and the impact of vehicle - track interaction. SP1 is to assist in verifying the benefits of innovations and solutions proposed by other SPs across a range of present and future mixed traffic rail operations found across Europe.

The objectives of SP1 are to

1. Manage the collection of information in a standardised format for the types of vehicles and track that result in high cost for maintenance and renewal
2. Categorise the key degradation conditions chosen by the participating Infrastructure Managers (IMs)
3. Determine the root causes of these degradation conditions by modelling at an appropriate level
4. Provide technical data to enable the RAMS and LCC benefit of innovative solutions to be determined
5. Develop a relational database of information developed in SP1, SP6, and the innovation SPs
6. Verify that the technical solutions have successfully addressed the root causes within the railway system context, and are suitable for a wide range of present and future traffic conditions across Europe

As the forces developed at the wheel-rail interface are a fundamental driver of all modes of track degradation, it is essential that these forces can be accurately characterised if all the objectives are to be achieved.

The main subject of Deliverable D1.1.1 was the gathering of summary vehicle data of representative vehicles from the railways of partner countries. This data enabled the InnoTrack vehicles team to identify a selection of vehicles that could be representative of the characteristics of the full range of European railway vehicles.

This report identifies the range of generic vehicles which are to be made available as vehicles dynamics models for modelling vehicle – track interactions for the associated work packages and to help provide track degradation and LCC data. It also includes summary information on new, half-worn and fully worn wheel profiles which would be used in Higher Resolution Modelling (HRM).

The deliverable D1.1.3 “Final output datasets of vehicle characteristics for use in determining vehicle track forces” is incorporated into this report due to the similarity of the content.

2. Degradation and Cost Modelling

2.1 Modelling Track Degradation

The forms of degradation and failure of the infrastructure reported by IMs have been identified in Innotrack deliverable D1.4.1. The table of most significant track faults was headed by:

- Poor track geometry
- Unstable ground and sub-structure
- Rolling contact fatigue of rails
- Switch wear in S&C
- Rail wear and corrugations

To model these defects and the track degradation it is proposed that three levels of models will be required:

1. **Low Resolution Models (LRM)**

   These are easy to use models based upon general findings and trends and have wide application. They are typically spreadsheet based and use simple empirical relationships to predict degradation. They may include limited vehicle information, although this is not always the case.

2. **Middle Resolution Models (MRM):**

   These are medium accuracy models which require general technical competency and tend to be based on the general findings of high resolution models. They are good for parametric studies. They typically include a representation of vehicle behaviour based on parameters that give information about key vehicle variables (e.g. unsprung mass) or coefficients which describe aspects of the vehicle behaviour (such as how the suspension controls response to track irregularities). These coefficients may be obtained from detailed vehicle dynamics models as described below or from field data such as wayside monitoring stations.

3. **High Resolution Models (HRM):**

   These provide high accuracy and require significant technical expertise and very fine grain and detailed inputs. They are good for identifying causal factors and can be site specific. They tend to require inputs from vehicle dynamics models such as GENSYS or VAMPIRE; detailed models to predict rolling contact fatigue fit into this category.

This approach ensures that complex models (HRMs) are reserved for applications which warrant their use and a detailed understanding of the benefits of an innovation at a specific location is required. These can feed information and algorithms into either MRM or LRM global models for use in LCC evaluations.

2.2 The Role of Vehicle Models

Clearly the most detailed vehicle suspension characteristic information and models are required for HRMs. However, even for MRMs and LRMs information about P2 forces or primary yaw stiffness can often be required.

The aims of the Vehicle characteristics' workpackage, WP1.1 are to:

- Classify European vehicle types (categories) and their dynamic properties
- Select key vehicles for investigation of vehicle track interaction
- Collate vehicle dynamic data for key vehicles
- Ensure that worst case vehicles are represented

- Develop generic vehicles having dynamic properties representative of different vehicle categories
- Assist other sub projects in the selection of vehicle characteristics for modelling purposes

In WP1.2 IMs have provided track data from which representative track sections are being selected. These are to be used with the generic vehicle dynamic models which are the subject of this report. The representative track segments are being classified by type and are to be used in simulations of these representative segments of track for LCC evaluation. Actual segments of routes which have specific problems of failure and degradation are also being chosen by participating railways.

In WP1.3 outputs of WP 1.1 and 1.2 are to be combined together using models to simulate the dynamic behaviour of the generic vehicles when combined with the representative track segments to determine whole life degradation rates and enable LCC evaluation.

2.3 Results of Summary Data

Summary vehicle characteristic information was provided by some of the participant countries and additional data was added to this during December 2006 and January 2007. A spreadsheet of data obtained for the representative vehicles of each country, was provided in Appendix 3 of deliverable D1.1.1. The data included the ages, speeds and weights of vehicles. During these investigations it became clear that detailed suspension parameters would be difficult to obtain for many of the vehicles of interest. This was due to a number of reasons but included difficulty in obtaining parameters for relatively old vehicles and issues of commercial confidentiality of manufacturer's designs for newer vehicles. As the foregoing description makes clear, a critical issue is the verification of solutions for the broad range of European railway conditions. In order to understand these conditions, it is essential to ensure that the vehicle models used cover the range of types and suspension stiffnesses used. This tends to dictate against modelling only specific vehicles, as a large number of vehicle models would be required to cover the range of conditions. Generic vehicle models offer a solution to this problem.

A further issue to consider when choosing vehicle models is the likely impact of future vehicle design. There has been a trend of increasing mass and stiffness in passenger rolling stock and a desire to increase axleload for freight vehicles. This has a significant effect on the duty conditions imposed on track. Many degradation models are non-linear (typically square law) relationships and therefore modest increases in mass and stiffness may lead to a significant increase in degradation. Consideration of future vehicle design is therefore critical when determining the type of track structure and components which will provide optimised life cycle costs. Generic vehicle models may be adapted to represent vehicles that have not yet been designed, provided the characteristics of these vehicles can be predicted. Also the advantages to the IMs in terms of reduced track degradation of reversing the trend to increased mass and primary yaw stiffness may be demonstrated. Examples of recent trends in increasing vehicle mass and primary yaw stiffness for vehicle in the UK are shown in Figures 2.1 and 2.2.

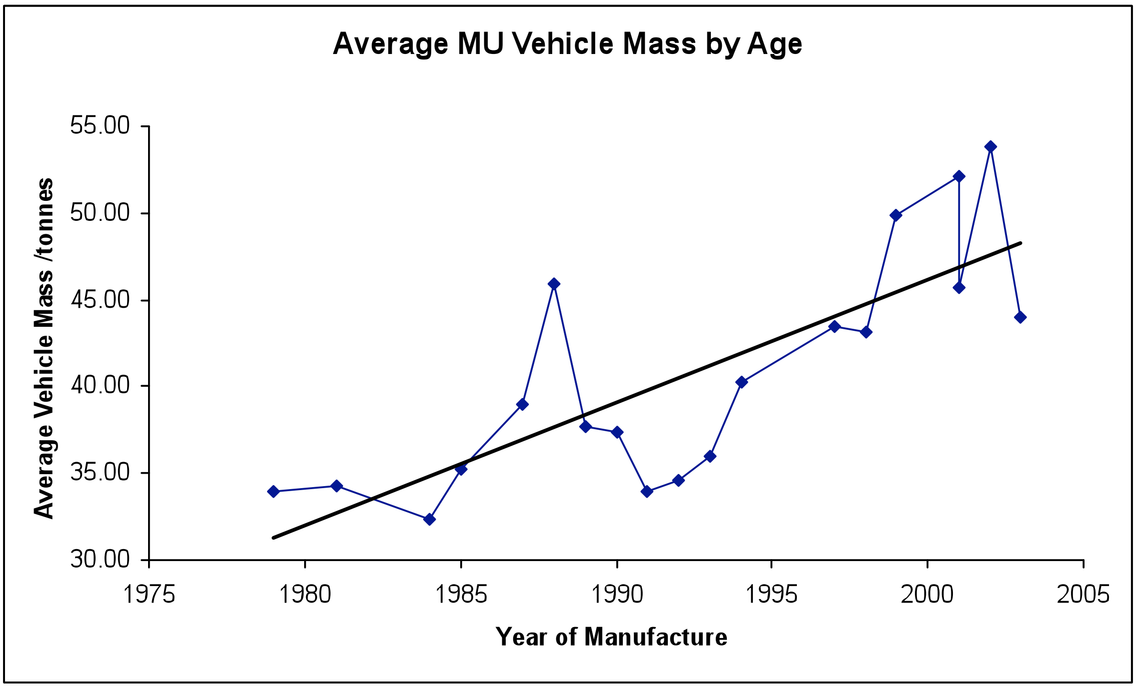


Figure 2.1: Average Mass of UK Multiple Units, 1979 – 2005

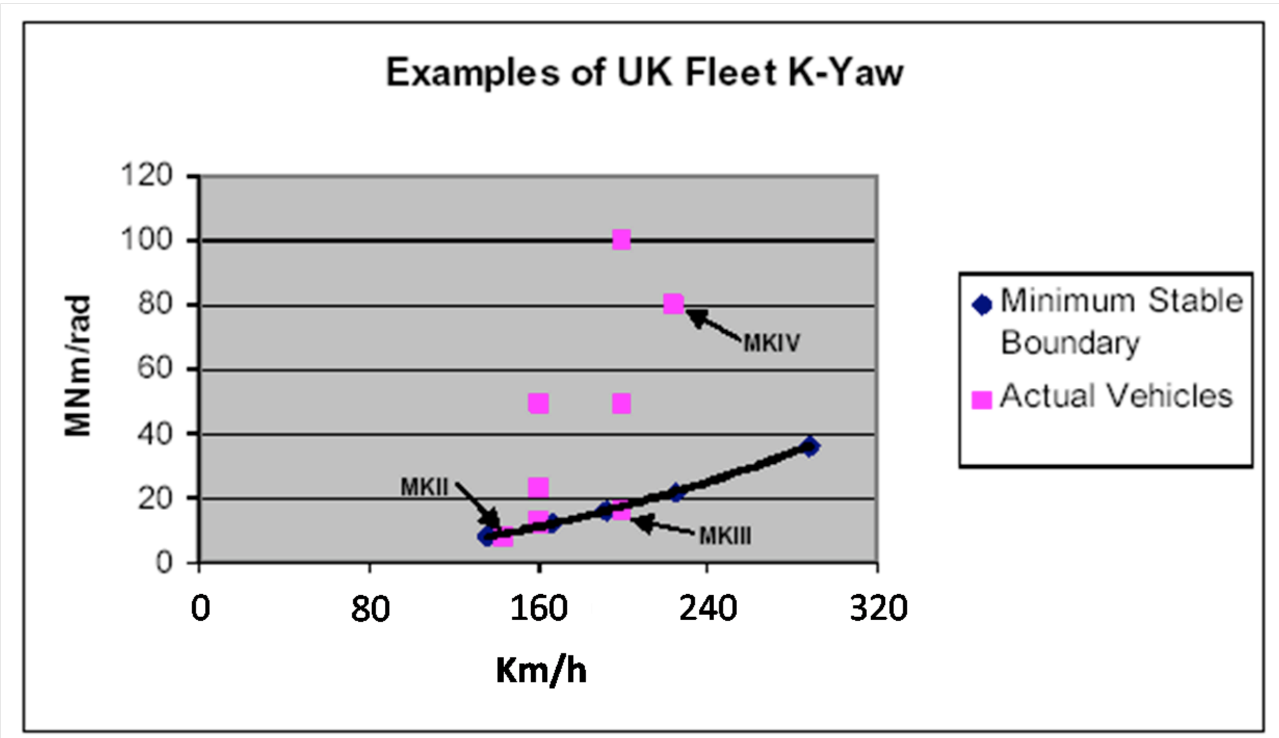


Figure 2.2: Examples of UK Vehicle Primary Yaw Stiffness with
Theoretical Stability Boundary for UK Wheel-Rail Conditions

3. Generic Vehicle Models

3.1 Overview of Generic Vehicle Dynamic Models

Generic vehicle models are used to represent a vehicle type for which insufficient data is available to develop a full model. They are ideal for examining the effect of parametrically varying one or more of the vehicle parameters which influence track degradation. These would normally include suspension stiffnesses (in particular primary yaw stiffness which is a key parameter in the generation of steering / curving forces), vehicle mass, unsprung mass, bogie pivot spacing, wheelbase and body center of gravity height. Generic vehicle models may be nearly as detailed as a full vehicle model or, for certain applications, contain considerable simplifications. There are several instances where generic model results have been compared with and successfully tuned to results from a full vehicle model, which a commercial partner has not wanted to make available.

Generic vehicle dynamics models usually use the following ***known*** parameters for the vehicle:

- Mass
- Bogie wheelbase and pivot spacing
- Wheel diameter
- Overall suspension type /layout (trailing arm, bolsterless bogie etc.)
- New wheel profile
- As much geometry information as available
- A reasonable estimate of the PYS

Generic rail vehicle models usually estimate the following parameters:

- Body, bogie and wheelset inertias
- Geometry of various suspension pickup points
- Primary and secondary lateral and vertical stiffness
- Primary and secondary lateral and vertical damping
- Bumpstop stiffness
- Parasitic stiffness, damping, series stiffness, dynamic stiffening and referred inertia effects
- Worn wheel profiles

Generic models often replace complex / non-linear suspension elements with simple / linear ones (e.g. airsprings, dampers, trailing arm bushes, bumpstops). This does not generally present a problem, as these simplifications tend to effect issues such as passenger comfort rather than the overall forces transmitted to the track. However, care should be taken to ensure that this statement remains the case when undertaking individual HRM studies. Limitations of generic models are discussed further below.

An example of a generic model, in this case representing an electric locomotive, is given in Figure 3.1. An issue which may arise during Innotrack modelling work is the need to transfer vehicle models between different software codes used by project partners. These include Vampire, Gensys, Adam/Rail, Simpack etc. The models themselves are not transferable, but a list of parameters describing each model will be made available which makes construction in each software code a straightforward task.

Although not specific to generic models, it is worthwhile to record the types of track models used in most vehicle dynamics software. These are generally simple 'lumped mass' models such as that illustrated in Figure 3.2. Whilst these have been proven to be acceptable for predicting wheel-rail forces, care should be exercised when considering higher frequency ranges or when inputting forces into a HRM of the track. In the former case it may be found that a model that include factors such as the structural stiffness and modal response of the track may be required; an example of this is the MMU / Corus Flexible Track System Model

(FTSM) which is being used in SP2. In the latter case care is required to avoid 'double counting' the effect of the pad and ballast stiffness which will be included in both the vehicle dynamics and HR track model.

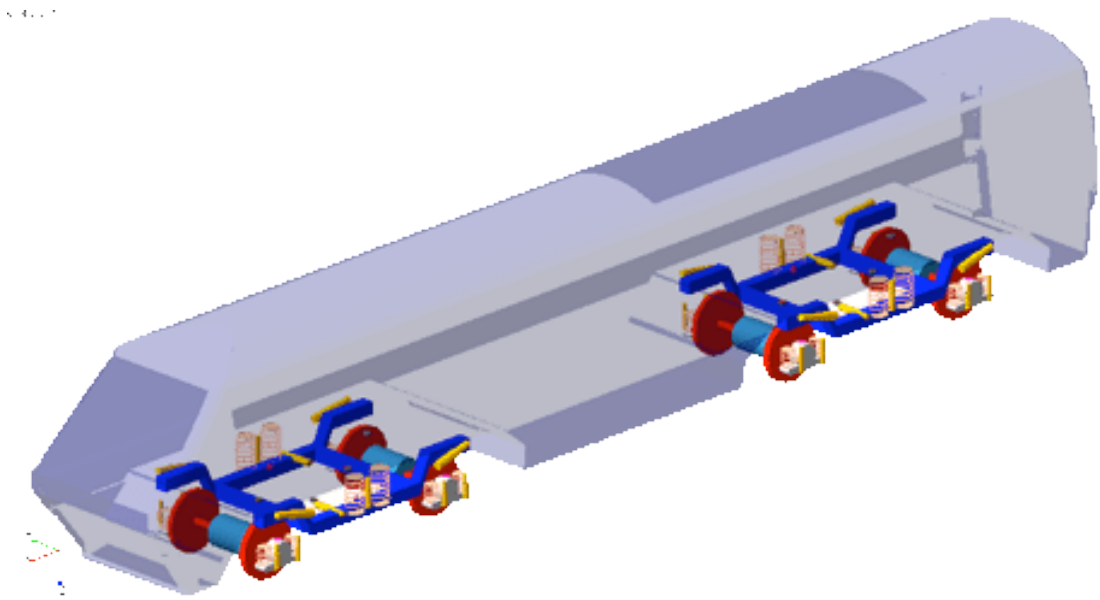


Figure 3.1: Example of an Electric Locomotive Generic Model (Adams/Rail)

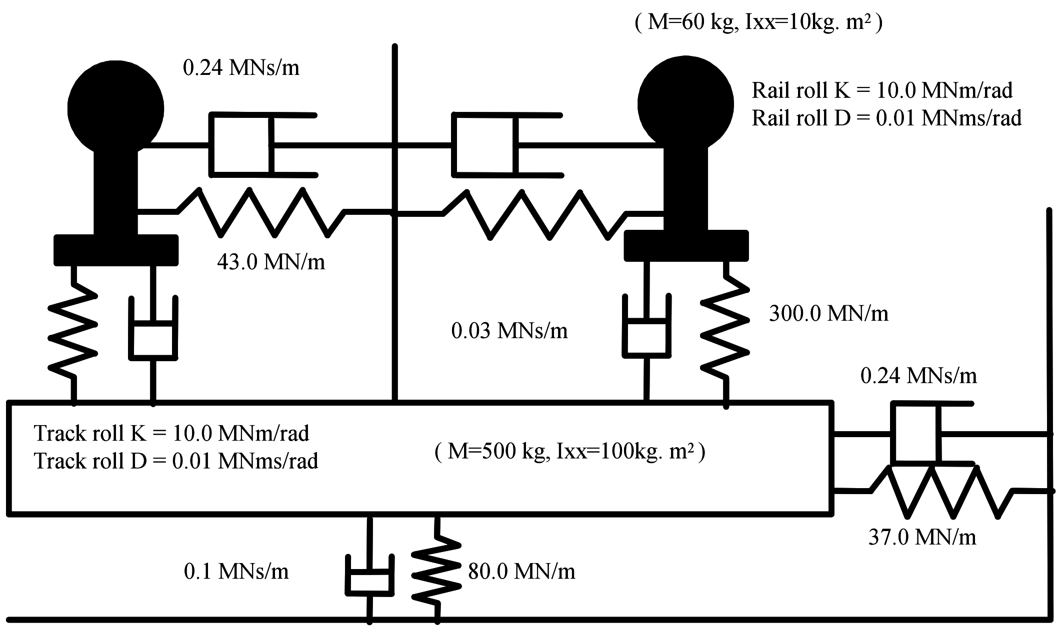


Figure 3.2: Typical Vehicle Dynamics 'Lumped Mass' Track Model

3.2 Limitations of Generic Models

As with any engineering model, care has to be taken to use generic models within their range of validity. Generic vehicle models work well with relatively linear suspension arrangements as found on most modern passenger vehicles. Even simplified elements representing steel coil springs, rubber chevrons and airsprings can give acceptable results in terms of track forces. Generic models are however poor at representing highly non-linear suspension arrangements, especially those containing friction elements. They are therefore less suitable for modelling freight vehicles and it is not proposed to use them to represent these vehicles. However, there are a number of widely used freight bogies / suspension designs (e.g. Y25 bogies and UIC link suspensions) and a small number of vehicle models can therefore be used to represent large fleets of wagons.

Generic vehicle models may not represent the behaviour of individual vehicle types well if the vehicle is near or beyond its stability boundary. However, as normal vehicle design should provide a significant stability margin this is not considered a serious limitation for work in Innotrack. It should be noted that for accurate wheel-rail forces and curving performance a reliable estimate of Primary Yaw Stiffness is required. Where this is not available it is necessary to undertake a parametric study to cover the range of possibilities. A further possibility is to obtain estimates of Primary Yaw Stiffness from wayside force measuring equipment. This issue is being explored in relation to the equipment provided by Innotrack project partner Damill.

Generic vehicle models are clearly not suitable for issues related to detailed behaviour of a specific vehicle type or design. Caution is also required when examining the steering forces / RCF propensity of modern passenger bogies with short trailing arm suspensions. The predicted forces can be significantly influenced by the geometrical set up of the suspension, as can the vehicle stability. This is due to the fact that the trailing arm geometry can be arranged such that bogie roll will reduce the angle of attack and therefore the steering forces generated. Similarly, poor geometrical set up can cause the wheelset angle of attack to increase. This effect is normally only significant on short trailing arm suspensions where a given amount of bogie roll can produce a useful change in angle of attack.

Figure 3.3 represents a range of five generic vehicle types modeled in a range of different characteristics 1 to 3. The vertical axis represents a range of track segment characteristics on which the generic vehicle types could operate. From a relatively small number of vehicle models and track segments wheel-rail forces that are representative of a wide range of European conditions may be simulated. This process requires verification from the innovation SP partners for the particular conditions of track and traffic that they are studying.

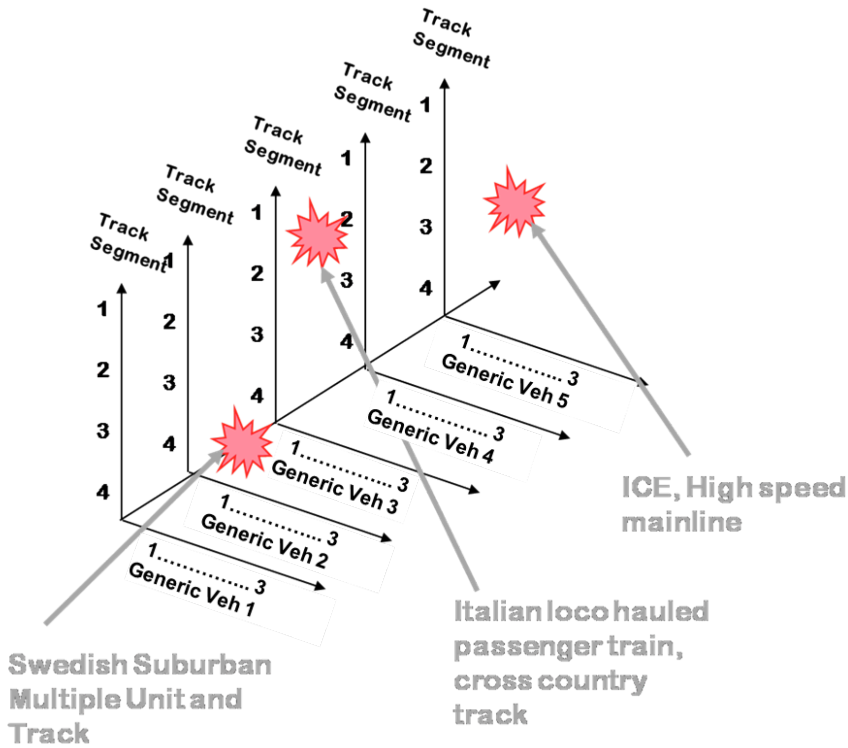


Figure 3.3: Use of Generic Vehicles and Track Segments to Represent a Range of European Conditions

3.3 The Selected Generic Vehicle Models

Deliverable D1.1.1 proposed a list of typical European vehicles which are to form the basis for the generic vehicle models which include:

- Multiple unit
- Bo-Bo locomotive
- Inter-city passenger coach
- Double deck suburban coach / multiple unit
- Inter city train (Pendolino)
- Y25 bogie wagon (container flat / tank wagon)
- UIC link suspension freight van

The proposed ranges of parameters for 5 of the characteristics for each of the proposed generic vehicle models (speed, axleload, yaw stiffness, unsprung mass and length) are given in Annex 1. Diagramatic representations for five of these generic vehicles are also given in Annex 1.

It is proposed that for each category of vehicle (e.g. multiple units) three different vehicle models will be created:

- A representative vehicle using many of the mean characteristics
- A low impact vehicle using most of the minimum characteristics
- A high impact vehicle using mostly using the maximum characteristics

It is proposed that the remaining parameters of each vehicle are fixed.

4. Wheel and Rail Profiles

4.1 Data Gathering

Wheel / Rail profiles

Simulation results for the same case vary greatly depending on the wheel and rail profiles chosen. It has therefore been important to establish the most widely used wheel and rail profiles used amongst partners. The criticality of this aspect is dependent on the purpose for which simulation results are being used. For example it is less critical for predicting load spectra to be used in designing track sub-structure and more critical for modelling RCF and the effectiveness of grinding.

Examples of the variety of rail profiles encountered may be found in Annex 2. Contact conditions are also significantly effected by the installed inclination of the rail which vary between 1:20 (UK and France), 1:30 (Sweden) and 1:40 (much of continental Europe). A wide variety of wheels are also used, the nearest to a common profile being the UIC S1002 profile widely employed across a range of European railways. An example of this profile is shown in Annex 3.

4.2 Worn Profiles

Although new wheels rail profiles provide a useful starting point, they are not generally representative of the 'average' contact conditions prevailing. Wheel profiles tend to wear to the average worn shape of the rail and vice-versa. This can, indeed usually does, give rise to significantly different contact conditions from the new case and as wear rates of new wheels and rails are often fairly rapid, the new contact condition are not representative of the majority of contacts. Exclusive use of new profiles can therefore lead to misleading simulation results. It has therefore been important to gather data on moderately worn and fully worn wheel profiles for particular types of service. A further complication in this respect is that for any given profile the worn shape can vary significantly depending upon a number of factors which include:

- Suspension type / stiffness
- Brake type (disc or tread)
- Route curvature
- Speed
- Lubrication (applied or natural – varying weather can ,lead to seasonal variations in wheel wear)
- Maintenance regime (rail grinding and wheel turning frequency)

It is clear that modelling within Innotrack cannot hope to cover the range of possibilities. However, it is intended that the data gathered will represent an advance on modelling using new profiles alone.

Manchester Metropolitan University have a large database containing around 2500 examples of UK passenger vehicle profiles from new to fully worn. However, the profiles measured are all P8 profiles. P8 is a moderate conicity profile that is not representative of the generally lower conicity combinations used across Europe. Examples of measured worn profiles from this database are presented in Figure 4.1 together with the development of wear with mileage in Figure 4.2. Note that these plots are for a tread braked vehicle.

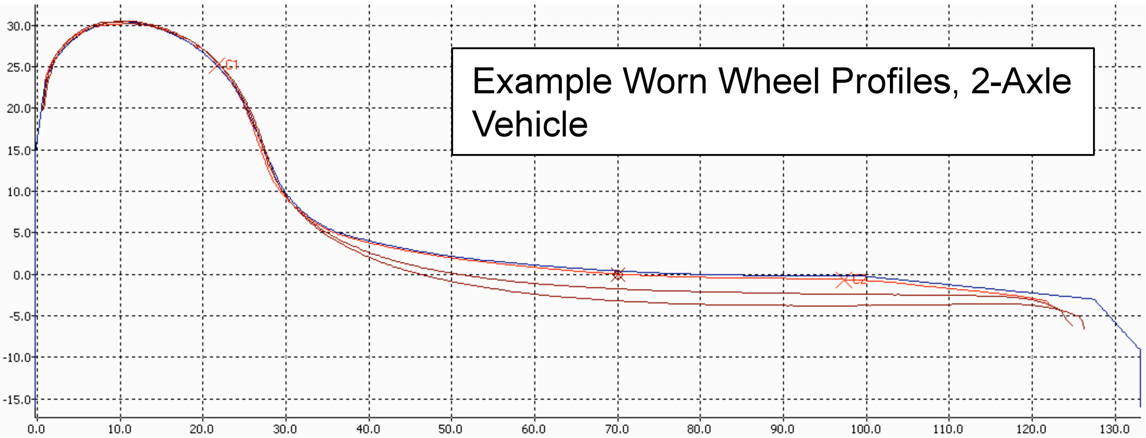


Figure 4.1: Example Worn Wheel Profiles, 2-Axle Tread Braked Vehicle

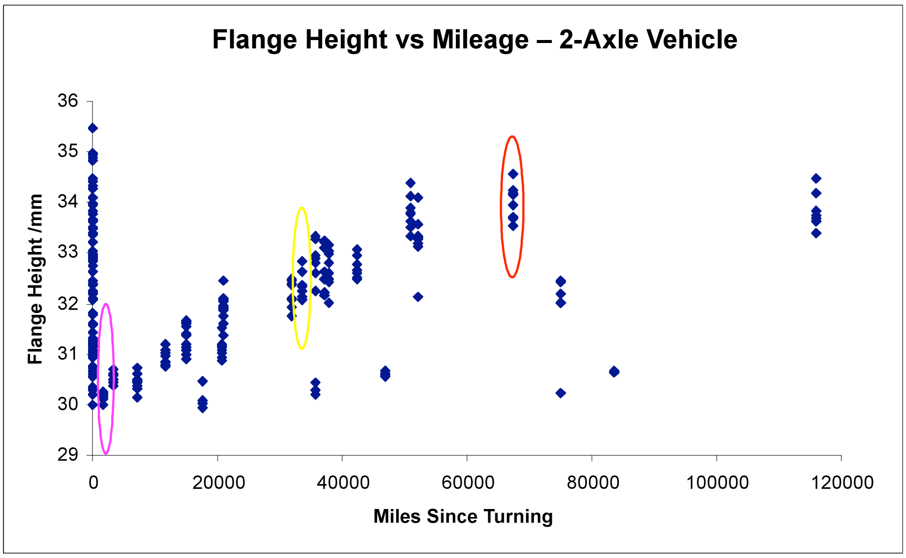


Figure 4.2: Example of Development of Wheel Wear, 2-Axle Tread Braked Vehicle

A selection of wheel profiles for various stages of tread wear for S1002 has been obtained from BV and it is planned to expand this database further by collecting measured worn wheel profiles from other Innotrack partners. A set or sets of generic rail profiles with increasing wear for increasing curvature is also required for successful High Resolution Modelling.

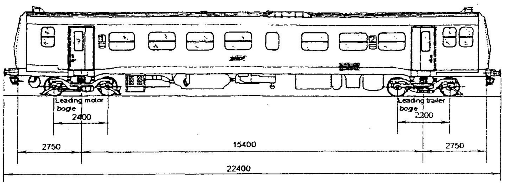
5. Conclusions

1. A range of vehicle characteristics has been proposed for representing the range of characteristics found for seven types of European rolling stock
2. For each of the seven types of European vehicles three different Generic Models will be developed for use in degradation modelling and Life Cycle Cost analysis in Innotrack.
3. Generic Models can also be made available to the other SPs to determine how effective their innovations are with a full range of European vehicles and track conditions
4. The first Generic Vehicle Model for a Multiple Unit has been developed
5. Libraries of wheel and rail profile data are being collected from partners to ensure that the High Resolution Modelling correctly models the full range of conditions found in Europe

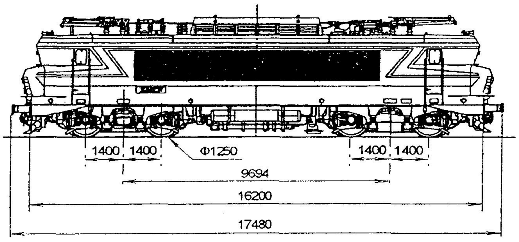
6. Annexes

Annex 1: Range of Generic Vehicle Characteristics

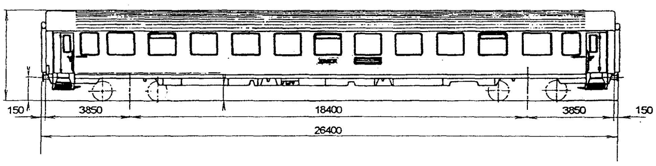
	Axleload (t)			Speed (km/h)			Yaw Stiffness (MNm/rad)			Unsprung Mass (t)			Vehicle length (m)		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Multiple Unit	9.5	11.2	14	100	160	200	12	30	50	1.4	1.6	2	20	23	26.5
Double Decker Coach/MU	11	14	17.5	140	160	200	20	35	60	1.5	1.8	2	23	25	27
Inter City Passenger Coach	9	10.8	12.3	140	180	200	8	17	30	1.1	1.8	1.9	20	23	26.5
Bo-Bo Locomotive	17.5	21.8	22	140	180	230	20	30	30	2.3	2.8	3	15.8	17.8	19.5
Inter City Train (Pendolino?)	13.5	13.5	14	200	225	250	10	25	40	1.4	1.6	2	20	23.8	26.5
Freight vehicle 4-axle Y25 bogie	10	22.5	25	65	100	120	n/a	n/a	n/a	1.3	1.6	1.8	14	20	23.7
Freight vehicle 2-axle UIC link suspension	10	22.5	25	55	100	120	n/a	n/a	n/a	1.3	1.6	1.9	10	15.5	17



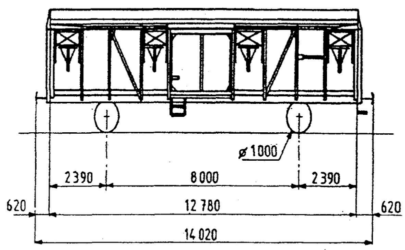
Multiple Unit (Single Vehicle Shown)

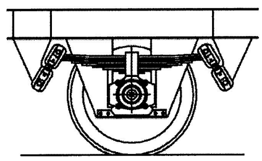


Bo-Bo Locomotive

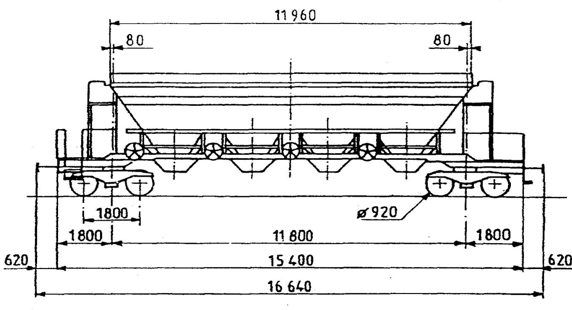


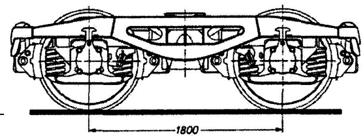
Inter-City Passenger Coach





2-Axle Van (UIC Link Suspension)





Y25 Bogie Wagon

(Hopper Shown)

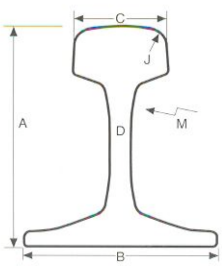
Figure A.1.1: Diagrammatic Representation of Generic Vehicle Types (Pendolino / Double Deck Coach not shown)

Annex 2: Range of European Rail Profiles

(Information courtesy of Corus Rail)

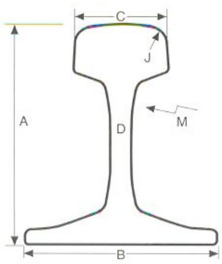
CEN Design Rail Sections

		46E 1 (previously SBB1)	46 E 2 (previously U33)	46 E 3 (previously NP46)	46 E 4 (previously UNI46)	49 E 1 (previously DIN S49)
Head crown Single radius mm Double radius mm		300/80	200/60	300/80	400 •	300/80
Gauge corner Radius	J= mm	13	13	13	14	13
Head width Taper		Parallel	1:20	1:16.5	1:20	1:17.2
Upper Fishing taper		1:4	1:3	1:4	1:4	1:3
Upper fillet Radius	mm	6/30	7	6	5	7
Web Parallel Radius	mm	Yes	Yes	Centre portion only 80/120	Centre portion only	Centre portion only 80/120
Lower fillet Radius	mm	6/30	7	6	5	7
Lower Fishing taper		1:4	1:3	1:4	1:4	1:3
Outer Flange taper		1:4	1:10	1:4	1:4	1:7.81
Rail height A	mm	145	145	142	145	149
Foot width B	mm	125	134	120	135	125
Head width C	mm	65	62	73.72	65	67
Min web thickness D	mm	14	15	14	14	14
Head area	mm^2	2543	2510	2671	2586	2982
Web area	mm^2	1192	1121	1175	1157	1106
Foot area	mm^2	2147	2263	2097	2235	2204
Total area	mm^2	5882	5894	5944	5978	6292
Section weight	kg/m	46.17	46.27	46.66	46.9	49.39
Moment of inertia Ixx	cm^4	1,641.1	1,642.7	1,605.9	1,688	1,816
Section modulus zxx	cm^3	217	213	224.2	221.6	240.3
Distance of neutral axis from top of rail	mm	75.65	77.14	71.64	76.16	75.59
Moment of inertia Iyy	cm^4	298.2	329.3	307.5	338.6	319.1
Section modulus Zyy	cm^3	47.7	49.1	51.3	50.2	51



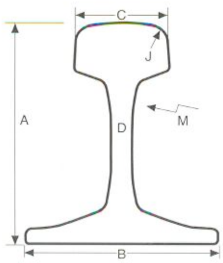
CEN Design Rail Sections

		49 E 2 (previously S49T)	49 E 3 (previously DIN S49b)	49 E 4 (previously Hush 113lb/54kg)	50 E 1 (previously U50E)	50 E 2 (previously 50 EB-T)
Head crown Single radius mm		400				
Double radius mm			300/80	300/80	200/60	300/80
Gauge corner Radius	J= mm	14	13	13	13	13
Head width Taper		1:16	1:15.2	1:20	1:20	1:20
Upper Fishing taper		1:3	1:3	1:2.75	1:3	1:3
Upper fillet Radius	mm	7	7	8/22	12	8/30.81
Web Parallel		Centre portion only	Centre portion only	Centre portion only	Yes	Yes
Radius	mm	80/120	80/120			
Lower fillet Radius	mm	7	7	16	12	30.81/3
Lower Fishing taper		1:3	1:3	1:2.75	1:3	1:3
Outer Flange taper		1:7.81	1:7.81	1:10	1:10	1:8
Rail height A	mm	148	146	110	153	151
Foot width B	mm	125	125	140	134	140
Head width C	mm	67	67	70	65	72
Min web thickness D	mm	14	14	22	15.5	15
Head area	cm^2	2946	2773	2876	2745	2608
Web area	cm^2	1106	1106	838	1273	1279
Foot area	cm^2	2204	2204	2590	2397	2478
Total area	mm^2	6,255	6,083	6,304	6,416	6,365
Section weight	kg/m	49.1	47.8	49.5	50.37	49.97
Moment of inertia Ixx	cm^4	1,796.3	1,705	875.1	1,987.8	1,988.8
Section modulus zxx	cm^3	239.4	227.2	145.9	246.7	248.5
Distance of neutral axis from top of rail	mm	75.03	75.05	59.98	80.56	80.04
Moment of inertia Iyy	cm^4	318.4	310.8	417.4	365	408.4
Section modulus Zyy	cm^3	50.9	49.7	59.6	54.5	58.3



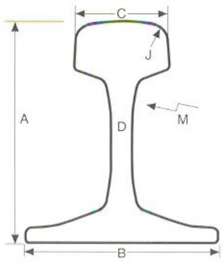
CEN Design Rail Sections

		50E 3 (previously BV50)	50E 4 (previously UIC50)	50 E 5 (previously UNI50)	50 E 6 (previously U50)	52 E 1 (previously 52 RATP)
Head crown Single radius mm Double radius mm		300/80	300/80	400	200/60	350
Gauge corner Radius	J= mm	13	13	14	13	12
Head width Taper		1:20	1:20	1:16	1:20	Parallel
Upper Fishing taper		1:3	1:2.75	1:3	1:3	1:2
Upper fillet Radius	mm	7	8/22	7	12	12
Web Parallel Radius	mm	450	508	Centre portion only 80/120	Yes	400/600
Lower fillet Radius	mm	7	15	7	12	12
Lower Fishing taper		1:3	1:2.75	1:3	1:3	1:2
Outer Flange taper		1:8.31	1:8.01	1:8	1:10	1:10
Rail height A	mm	155	152	148	153	150
Foot width B	mm	133	125	135	140	150
Head width C	mm	70	70	67	65	65
Min web thickness D	mm	14	15	14	15.5	15
Head area	cm^2	2836	2901	2946	2745	2959
Web area	cm^2	1295	1358	1106	1273	1102
Foot area	cm^2	2240	2169	2310	2465	2583
Total area	mm^2	6,371	6,428	6,362	6,484	6,643
Section weight	kg/m	50.02	50.46	49.9	50.9	52.15
Moment of inertia Ixx	cm^4	2,057.8	1,934	1,844	2,017.8	1,970.9
Section modulus zxx	cm^3	259.5	252.3	242.1	248.3	247.1
Distance of neutral axis from top of rail	mm	79.3	76.64	76.15	81.26	79.76
Moment of inertia Iyy	cm^4	351.3	315.2	362.4	396.8	434.2
Section modulus Zyy	cm^3	52.8	50.4	53.7	56.7	57.9



CEN Design Rail Sections

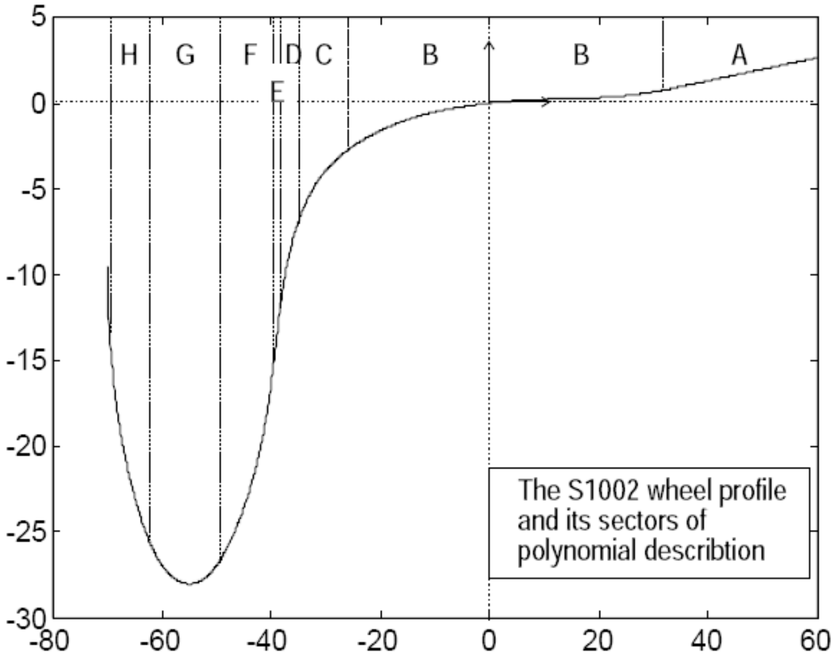
		54E 1 (previously UIC54)	54 E 2 (previously UIC54E)	54 E 3 (previously DIN S54)	55 E 1 (previously U55)	56 E 1 (previously RT113A)	60 E 1 (previously UIC60)
Head crown Single radius mm Double radius mm		300/80	300/80	300/80	200/60	305/80	300/80
Gauge corner Radius	J= mm	13	13	13	13	12.7	13
Head width Taper		1:20	1:20	1:17.2	1:20	1:20	1:20
Upper Fishing taper		1:2.75	1:2.75	1:3	1:3	1:2.75	1:2.75
Upper fillet Radius	mm	8/22	8/22	16	12	8	7/35
Web Parallel					Yes	Yes	Centre portion only
Radius	mm	508	508	500			120
Lower fillet Radius	mm	16	16	16	12	15	35/7
Lower Fishing taper		1:2.75	1:2.75	1:3	1:3	1:2.75	1:2.75
Outer Flange taper		1:10	1:10	1:7.81	1:10	1:10	1:14
Rail height A	mm	159	161	154	155	158.75	172
Foot width B	mm	140	125	125	134	140	150
Head width C	mm	70	67.01	67	62	69.85	72
Min web thickness D	mm	16	16	16	19	20	16.5
Head area	cm^2	2901	2942	3223	2897	286	3084
Web area	cm^2	1486	1486	1338	1465	1712	1730
Foot area	cm^2	2590	2428	2391	27.75	2597	2856
Total area	mm^2	6,977	68.56	6,952	7,137	7,169	7,670
Section weight	kg/m	54.77	53.82	54.57	56.03	56.3	60.21
Moment of inertia Ixx	cm^4	2,337.9	2,307	2,074	2,150.4	2,321	3,038.3
Section modulus zxx	cm^3	278.7	276.4	262.8	255.2	275.5	333.6
Distance of neutral axis from top of rail	mm	83.87	83.47	78.93	84.26	84.24	91.08
Moment of inertia Iyy	cm^4	419.2	341.5	354.8	418.4	421.6	512.3
Section modulus Zyy	cm^3	59.9	54.6	56.8	62.4	60.2	68.3



U.I.C. and A.S.C.E. Design Rail Sections

		U.I.C.			A.S.C.E.			
		50	54	60	40	60	75	80
Head crown								
Single radius 12in					•	•	•	•
Double radii 300 & 80mm		•	•	•				
Gauge corner								
Radius	J= $^{5}/_{16}$ in.				•	•	•	•
Radius	J= 13mm	•	•	•				
Head width								
Parallel					•	•	•	•
1:20 taper		•	•	•				
Fishing tapers								
Upper & lower	13° = 1:4.3				•	•	•	•
Upper & lower	1:2.75	•	•	•				
Fillet radii								
Upper & lower	$^{1}/_{4}$ in.				•	•	•	•
Upper	mm	8 & 22	8 & 22	7 & 35				
Lower	mm	15	16	7 & 35				
Foot								
Double tapered		•	•	•				
Outer taper		1:8	1:10	1:14				
Web								
Fully radiused	M=12" Rad.				•	•	•	•
Fully radiused	M = 508mm Rad.	•	•					
Upper & lower	radii 120mm			•				
Centre parallel								
Rail height A	in.				$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{13}{16}$	5
	mm	152	159	172	88.90	107.95	122.24	127.00
Foot width B	in.				$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{13}{16}$	5
	mm	125	140	150	88.90	107.95	122.24	127.00
Head width C	in.				$1\frac{7}{8}$	$2\frac{3}{8}$	$2\frac{15}{32}$	$2\frac{1}{2}$
	mm	72.2	72.2	74.3	47.63	60.33	62.71	63.50
Min web thickness D	in.				$\frac{25}{64}$	$\frac{31}{64}$	$\frac{17}{32}$	$\frac{35}{64}$
	mm	15	16	16.5	9.92	12.30	13.49	13.89
Head area	in.^{2}				1.64	2.49	3.07	3.30
	mm	2899	2899	3085	1059	1603	1981	2129
Web area	in.^{2}				0.85	1.24	1.54	1.64
	mm^2	1318	1486	1730	547	803	996	1059
Foot area	in.^{2}				1.48	2.21	2.72	2.93
	mm^2	2169	2590	2856	953	1426	1756	1890
Total area	in.^{2}				3.97	5.94	7.34	7.87
	mm^2	6385	6975	7672	2559	3832	4733	5078
Section weight	lb/yd				40.50	60.64	74.90	80.36
	kg/m	50.12	54.75	60.22	20.09	30.08	37.18	39.86
Moment of inertia Ixx	in.^{4}				6.58	14.58	22.92	26.45
	cm^4	1930	2336	3039	274	607	954	1101
Section modulus Zxx	in.^{3}				3.58	6.61	9.11	10.09
	cm^3	251	278	334	59	108	149	165
Distance of neutral axis from top of rail	in.				1.84	2.20	2.51	2.62
	mm	76.89	83.90	91.06	46.64	55.98	63.9	66.59
Moment of inertia Iyy	in.^{4}				1.60	3.61	5.42	6.21
	cm^4	314	419	513	67	150	226	259
Section modulus Zyy	in.^{3}				0.91	1.70	2.25	2.49
	mm^3	50	60	68	15	28	37	41

Annex 3: S1002 Wheel Profile



The sections of the S1002 profile shown above are defined by the following polynomials:

$$
\begin{aligned}
\text{Section A:} \quad F(s) &= a_A - b_A s \\
\text{Section B:} \quad F(s) &= a_B - b_B s + c_B s^2 - d_B s^3 + e_B s^4 - f_B s^5 + g_B s^6 - h_B s^7 + i_B s^8 \\
\text{Section C:} \quad F(s) &= -a_C - b_C s - c_C s^2 - d_C s^3 - e_C s^4 - f_C s^5 - g_C s^6 - h_C s^7 \\
\text{Section D:} \quad F(s) &= a_D - \sqrt{b_D^2 - (s + c_D)^2} \\
\text{Section E:} \quad F(s) &= -a_E - b_E s \\
\text{Section F:} \quad F(s) &= a_F + \sqrt{b_F^2 - (s + c_F)^2} \\
\text{Section G:} \quad F(s) &= a_G + \sqrt{b_G^2 - (s + c_G)^2} \\
\text{Section H:} \quad F(s) &= a_H + \sqrt{b_H^2 - (s + c_H)^2}
\end{aligned}
$$

and

	A	B	C	D
a	1.364323640	0.0	$4.320221063\,10^{+3}$	16.446
b	0.066666667	$3.358537058\,10^{-2}$	$1.038384026\,10^{+3}$	13.
c	–	$1.565681624\,10^{-3}$	$1.065501873\,10^{+2}$	26.210665
d	–	$2.810427944\,10^{-5}$	$6.051367875\,10^{+0}$	–
e	–	$5.844240864\,10^{-8}$	$2.054332446\,10^{-1}$	–
f	–	$1.562379023\,10^{-8}$	$4.169739389\,10^{-3}$	–
g	–	$5.309217349\,10^{-15}$	$4.687195829\,10^{-5}$	–
h	–	$5.957839843\,10^{-12}$	$2.252755540\,10^{-7}$	–
i	–	$2.646656573\,10^{-13}$	–	–
$\xi_{\min}$	32.15796	-26	-35	-38.426669071
$\xi_{\max}$	60	32.15796	-26	-35

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