Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of the Environment, Transport, Energy and Communications (DETEC)

Federal Office of Transport (BAV)
Finance department

Base Price Wear in the train-path pricing system

Instructions for determining vehicle prices

Publication details / Document control

Publisher: Federal Office of Transport (BAV), 3003 Bern, Finance department

Document name: Instructions for determining vehicle prices

Distributor: Published on BAV website

Versions in other languages: German (original), French, Italian

Effective date: These instructions come into force on 14th March 2022. They replace version 1.0 of 23rd August 2016

Record of changes

Version	Date	Changed by	Change notes	Document status
1.0	23.08.2016	FI/sn	1st edition	replaced
1.1	14.03.2022	FI/mz	Revision of the first edition	in force

Contents

1. Introduction

With the introduction of the base price wear into the new train-path pricing system (TPS) – effective as of 2017 – a method for calculating vehicle-specific prices is required in accordance with the Track Access Ordinance of the Swiss Federal Office of Transport (NZV-BAV; SR 742.122.4; available in German, French, Italian) [1]. This document provides the instructions for this calculation.

The following sections define the necessary processes for evaluating a vehicle. The document explains the background to the new approach and describes the steps of the calculation process. The relevant formulae and calculation aids are explained, but the document does not provide any information about billing.

2. Principles behind the base price wear

In order to ensure that the track maintenance costs included in the train-path price are based on usage, the train-path pricing system (TPS) 2017 introduces the base price wear. The principles behind the price calculation are illustrated in Figure 2-1.

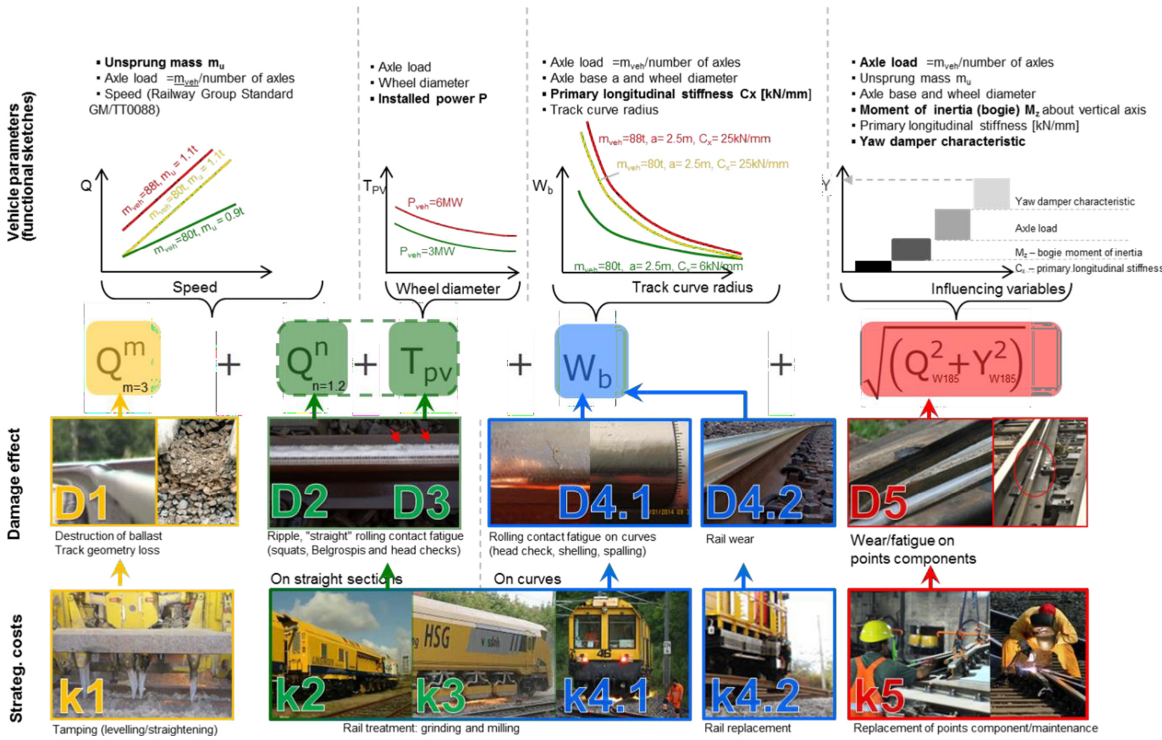


Figure 2-1: Allocation of damage mechanisms to resulting track maintenance work

The costs for track maintenance are incurred through maintenance measures such as tamping, rail treatment, rail replacement and points maintenance, which are shown in the bottom row of the figure. These are strategic costs for damage repair or preventative measures. All of these costs added together result in the total expenditure for the maintenance of a section of track. A distinction is made between straight and curved sections.

The reason for the maintenance measures is track damage, which is shown in the next row up. This damage is caused by the vehicles. However, not every vehicle contributes to track deterioration to the same extent. Different vehicle properties result in different degrees of interaction with the track. The following variables are seen to contribute to damage:

Q: Dynamic vertical wheel force
T_{pv}: Traction power value
W_b: Specific frictional energy in wheel-rail contact
Q_{W185}: Vertical force acting on the rail from the wheel when travelling over points
Y_{W185}: Lateral force acting on the rail from the wheel when travelling over points

These variables depend to some extent on the speed and the radius of the curve in the track. Their influence on the damage is formulated by means of laws of damage. These laws are explained in more detail in Section 6.3.

Cost calibration factors (k_j), which depend to some extent on the curve radius, are used to relate the damage (D_j) to the costs.

The 2017 train-path pricing system assigns the train paths to different radius bands according to their curve radii. Sections with a curve radius > 1200 m are counted as straight. They are divided into different speed bands. There are a total of 10 different bands (Table 2-1).

The base price wear which a vehicle must pay per km in one of these sections is calculated from the total of the damage multiplied by the cost calibration factors ($\sum_j k_j \cdot D_j$, with j=1, 2, 3, 4.1, 4.2, 5).

The Track Access Ordinance of the Swiss Federal Office of Transport (NZV-BAV) ([1], Annex 1a) describes the principle of the calculation with the following summarising formula:

$$C(V,R)_i = (k_1 \cdot F_{RQ} \cdot Q_f^{3} + k_2 \cdot Q_f^{1.2} + \alpha \cdot k_3 \cdot T_{pv} + k_4 \cdot F_{RW\ b} \cdot W_{bf} + k_5 \cdot \sqrt{f5_1 \cdot Q^2_{W185} + f5_2 \cdot Y^2_{W185}}) \cdot S$$

Formula 2-1: Principle formula for the base price wear in accordance with NZV-BAV [1]

$C(V,R)_i$ stands for the costs for the wear caused by the vehicle, i, at speed V with a track curve radius of R. These costs determine the vehicle price in the speed and radius bands (V/R bands for short). As the damage depends on the speed and curve radius, there is a differentiated price – with the unit CHF/km – for each band in the case of each vehicle.

The meaning of the scaling factor S is explained in the next section. Further verbal descriptions of the individual variables can be found in the NZV-BAV ordinance ([1], Annex 1a). The precise mathematical formulae for the calculation are defined and explained in Section 6.

2.1. Vehicle reference costs and vehicle price for billing

A fixed reference cost amount was set to determine the cost calibration factors (k_j). To determine the cost calibration factors, the costs per damage term were calibrated to these <u>reference costs</u> as a total over the vehicle fleet kilometers for the SBB normal-gauge network [6]. Figure 2-2 shows the percentages of the reference costs for the individual damage terms on the left-hand side.

The right-hand side of the figure shows the <u>marginal costs</u> (billable costs as defined by the Ordinance) which represent the total income from the base price wear. The scaling factor S is used to relate the reference costs to the marginal costs.

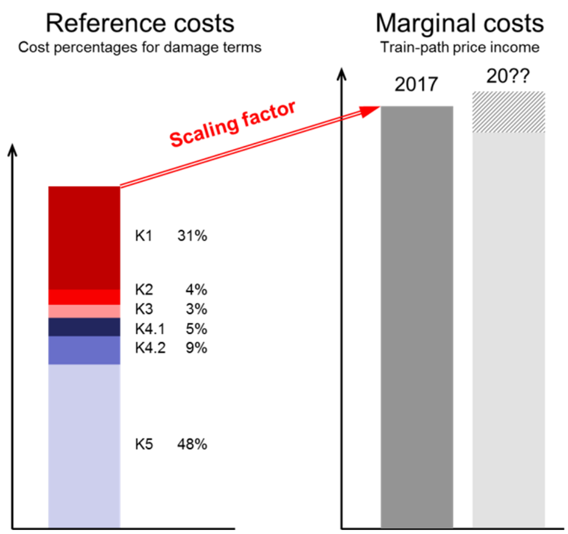


Figure 2-2: Scaling factor for converting reference costs to marginal costs

There are two terms relevant to each vehicle: the vehicle reference costs and the vehicle price (for the billing to cover the marginal costs).

The vehicle reference costs $Crel_{V/R}$ are fixed values which are calculated on a one-off basis and do not change again. They form the basis for comparisons.

The vehicle prices $C_{V/R}$ are the values used for train-path price billing. They are calculated from the vehicle reference costs and the scaling factor, which can change depending on the set marginal costs.

The table below summarises the abbreviations and terms used in connection with the prices:

Price band	Vehicle reference costs	Vehicle price (= billing price)
		$= S * Crel_{V/R}$
Radius > 1200 m		
V ≤ 80	$Crel_{V0\text{-}80}$	$C_{V0\text{-}80}$
80 < V ≤ 100	$Crel_{V80\text{-}100}$	$C_{V80\text{-}100}$
100 < V ≤ 120	$Crel_{V100\text{-}120}$	$C_{V100\text{-}120}$
120 < V ≤ 140	$Crel_{V120\text{-}140}$	$C_{V120\text{-}140}$
140 < V ≤ 160	$Crel_{V140\text{-}160}$	$C_{V140\text{-}160}$
160 < V ≤ 200	$Crel_{V>160}$	$C_{V>160}$
Radius ≤ 1200 m		
R ≤ 300	$Crel_{R<300}$	$C_{R<300}$
300 <R ≤ 400	$Crel_{R300\text{-}400}$	$C_{R300\text{-}400}$
400 < R ≤ 600	$Crel_{R400\text{-}600}$	$C_{R400\text{-}600}$
600 < R ≤ 1200	$Crel_{R600\text{-}1200}$	$C_{R600\text{-}1200}$

Table 2-1: Speed and radius bands for price differentiation, along with price designations

3. Procedure for determining the vehicle price

When a new vehicle joins the Swiss rail network, a network access license is issued. As part of this process, the RU/vehicle owner has the opportunity to have the price grading carried out for submission to the infrastructure, represented by SBB for the network looked after by its train-path sales department (OneStopShop).

3.1. Waiving vehicle price determination

It is not obligatory to determine the specific vehicle prices necessary for the train-path price calculation. If no prices are specified, "default prices" are used for the billing. The train-path price to be paid is then higher than the price calculated with vehicle prices entered, and is determined as a maximum value for vehicle groups with the same properties plus a surcharge. The valid default prices are recalculated annually. As the determination of vehicle prices is linked to certain costs, it may be sensible to waive this procedure under some circumstances.

Based on the Track Access Ordinance (NZV; SR 742.122) Art. 19a para. 6, there are special provisions applicable to historic vehicles in accordance with NZV-BAV Art. 1 para. 4c.

3.2. Time scale

Figure 3-1 shows how the vehicle price determination fits into the vehicle manufacturing and homologation process in terms of timings. When a new vehicle joins the Swiss normal-gauge network, it has to be homologated by the supervisory body. Preliminary pricing work can be carried out before the definitive homologation, but the final inspection and binding price activation (release for billing) only take place once the homologation has been issued. Pricing and homologation are, therefore, separate processes.

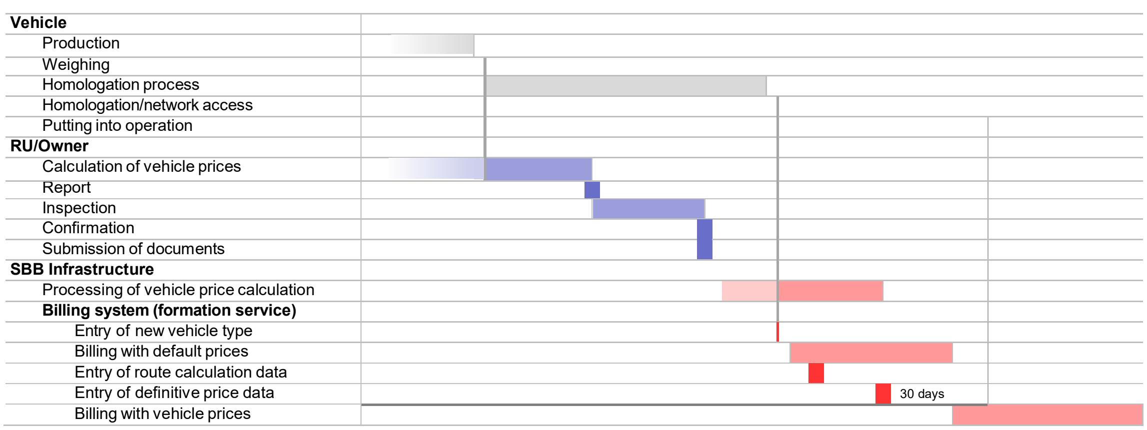


Figure 3-1: Basic time scale for determining the price of a new vehicle in the Swiss normal-gauge network

As the mass of the vehicle has a significant effect on pricing, the price calculation assumes a minimal validation of the vehicle data aligned with the weighing of at least one vehicle. At the time of weighing, the vehicle is in its standard operational condition (i.e. without equivalent masses for missing interior fittings, etc.). The mass calculations are verified for the price calculation on the basis of the measured weight data. This data can be used to calculate the vehicle prices for each V/R band (Section 6).

When the homologation is issued, the new vehicle type is entered in the formation service which provides the necessary data for the billing system. The vehicle can travel freely but the default price is used. If type tests with a scope of more than 15,000 km are planned as part of the homologation of a vehicle, bilateral regulations can be agreed with SBB Infrastructure with regard to the billing if required.

Once the necessary documents have been submitted to SBB Infrastructure, the vehicle price determination is processed (Section 3.3.3). When this check is complete, the definitive vehicle prices are stored in the billing system. After 30 days, the prices are activated and the train-path price is recalculated with the specific vehicle prices. The difference between the elevated default prices and the actual price of the vehicle shall not be refunded.

3.3. Price determination process

Figure 3-2 illustrates the pricing process and the parties involved.

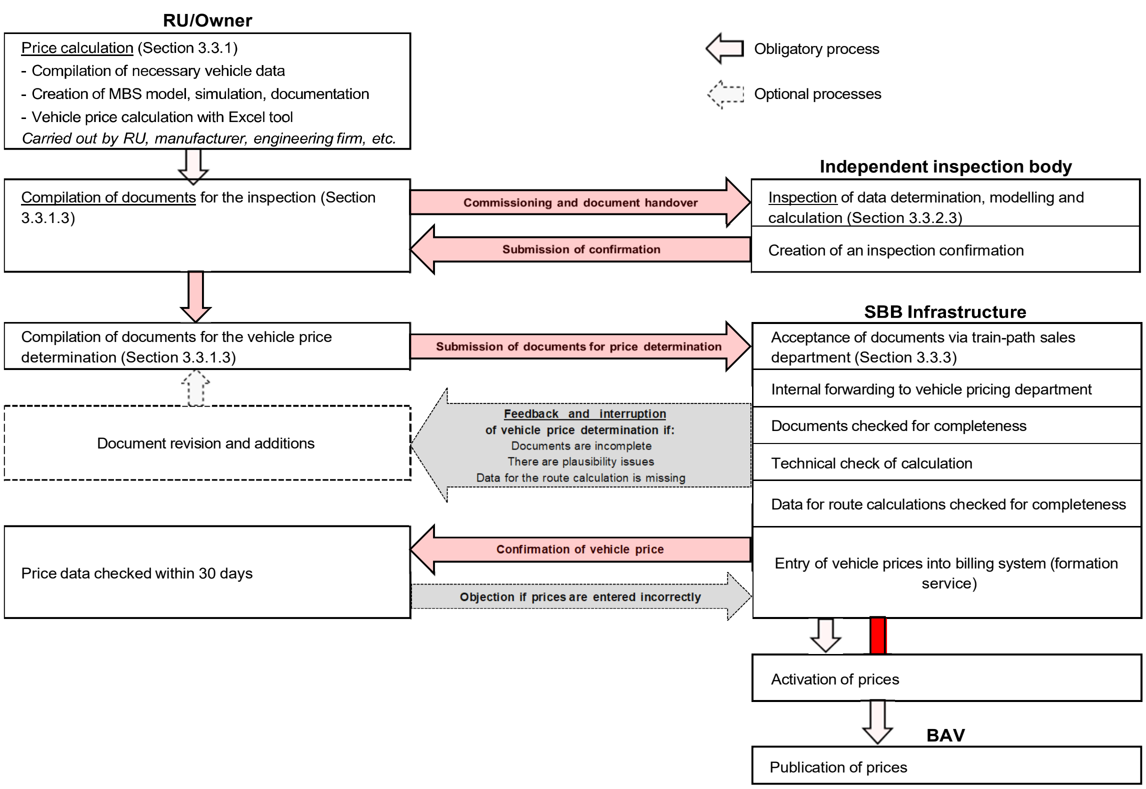


Figure 3-2: The pricing process

3.3.1. RU/Owner

The calculation of the vehicle price is initiated by the RU/vehicle owner. The RU/owner may perform the calculation themselves if they have the relevant qualifications (see 3.3.1.1) and knowledge of the data. If this is not the case, an external party may be appointed to carry out the calculation. This task may fall to the manufacturer of a new vehicle. Alternatively, an engineering firm or a different RU which can demonstrate the necessary qualifications may be appointed.

Once the calculation is complete, it is examined by an independent inspection body (Section 3.3.2) who issues the corresponding inspection confirmation.

An application is then made to SBB Infrastructure for the vehicle price determination and the necessary documents are submitted (see 3.3.1.3).

When submitting the inspection documentation (input data, inspection documentation), the RU assumes the obligation to ensure that the data is correct. By initiating the price determination procedure, the RU which submits the documentation or the designated manufacturer assumes responsibility for the inspection body appointed to determine the price and its calculations or the calculations of third parties.

3.3.1.1. Qualifications of the calculation agent

The employee responsible for calculating the vehicle prices must demonstrate the following qualifications:

- University degree in engineering or a mathematical/scientific subject
- More than 5 years' experience in the field of running gear engineering and vehicle homologation
- Evidence of extensive (more than 5 years') experience in modelling and calculating multi-body systems (MBS)

Persons who do not fully meet these requirements may still carry out the calculation if supervised by personnel with the appropriate qualifications.

As evidence of the qualifications, a brief profile of the employees involved in the calculation is submitted along with the documents.

3.3.1.2. Scope of the work to be carried out

The calculation agent collects the relevant vehicle parameters and compiles them in a parameter data set.

The process for carrying out the calculation is defined in Sections 6 to 8. These sections explain how to use the vehicle price calculator and describe how the multi-body simulations are to be performed.

If the vehicle's parameters are similar to those of a vehicle for which vehicle prices have already been determined, a parameter comparison is permitted (see Section 5.5). If the values are within the defined tolerances, a new multi-body system calculation is not required.

The necessary files are published on www.onestopshop.ch [9].

3.3.1.3. Documents

In order to check the calculation and apply for vehicle price determination, certain documents need to be compiled. The table below shows which documents need to be provided in each case.

Documents/data	Independent inspection body		SBB-I
	For submission	For inspection	For submission
Design drawings			
Vehicle layout drawing (with seating plan)	✓		✓
Running gear drawings - Overview - Primary level, wheelset guidance - Secondary level - Drive	✓		✓
Carbody drawings - Body connections - Joints/buffers	✓		✓
Component drawings - Spring elements - Dampers		✓	
Measurement results			
Weighing log	✓		✓
Parameter calculations			
Vehicle mass calculation		✓	
Running gear mass calculation		✓	
Stiffness calculations		✓	
MBS calculations			
Description of MBS model [a)]	✓		✓
Parameter data set for MBS model [b)]	✓		✓
MBS calculation report [a)]	✓		✓
MBS model [c)]	(✓)	(✓)	
MBS result files [a)]	✓		✓
Vehicle price calculation			
Completed vehicle price calculator (Excel)	✓		✓
Inspection body documents			
Inspection report			✓
Calculation report from the inspection body [d)]			✓
Comments			
a) Definition of the content in Section 7.4 b) Example in Annex (Section 12) c) Submission, inspection or remodelling in consultation with the inspection body (see Section 3.3.2.2) d) If the inspection body has carried out its own MBS modelling and calculation			

Table 3-1: List of required documents

This list is not exhaustive. If additional data is required for the inspection body or the SBB Infrastructure department to check the calculation, it may be necessary to submit additional documents.

3.3.2. Independent inspection body

A BAV-approved external body is responsible for checking that the work is carried out correctly.

3.3.2.1. Approval by BAV

Bodies can be approved as an independent inspection body by following the procedure detailed in the Annex (Section 13).

3.3.2.2. Scope of the inspection

The main task of the inspection body is to check that the vehicle parameters used in the calculation and MBS simulation are correct. To do this, the body must have access to the drawings and calculations from which the input data for the calculation is derived. This should be possible on the basis of the documents listed in Table 3-1.

In order to check the values determined via MBS simulations, the model must be checked and control simulations carried out. The easiest way to do this is to give the inspection body access to the MBS model so it can be checked.

If the calculation agent does not wish to disclose the model in order to protect the relevant knowledge, the calculations must be checked with a model created by the inspection body. The parameter data set given to the inspection body must be designed to enable remodelling of this nature. The calculations must then be documented as stated in Section 7.4.

Discrepancies in the results or the calculation procedure must be discussed with the calculation agent. In case of doubt, the SBB Infrastructure vehicle pricing department may be included in the discussion (contact details in Section 11.2).

3.3.2.3. Inspection report

The inspection body compiles a report describing the checks and control calculations carried out. The body must confirm that the regulatory specifications for the calculation and vehicle price determination have been observed.

3.3.3. SBB Infrastructure

The application for vehicle price determination and the necessary documents are submitted via the train-path sales department (contact details in Section 11.1). The train-path sales department forwards the documents to the internal SBB Infrastructure vehicle pricing department. This department then checks whether the documents are complete and sufficient for a plausibility check to be carried out. In the event of any objections, the department contacts the body that submitted the application.

As part of the determination process, an internal check is also carried out to verify whether the RU has provided all of the rolling stock data required for the operational management systems of SBB Infrastructure. This data is required for route calculations (ZLR) in the operational management systems and ensures trouble-free operational planning. More information can be found at www.onestopshop.ch [10]. If the data provided is not sufficient, the process can be interrupted until the necessary data is available.

Once the check has been completed without any objections, the calculated prices are entered in the price management system. The RU/owner receives confirmation that the prices have been entered and is given 30 days to check the prices and file an objection if they have been entered in the system incorrectly or if there are any other reasons not to activate the prices in the billing system. After 30 days, the prices are activated. The BAV receives the prices for publication.

The vehicle pricing department has the opportunity to request the publication of the current quantitative fleet distributions of vehicle types within the RU/owner via the BAV.

3.3.4. Rail transport commission RailCom

If discrepancies and differing standpoints arise during the vehicle pricing process, the vehicle pricing department contacts the RU/owner, the calculation agent and the inspection body in the first instance. If the price calculation is not accepted and an agreement cannot be reached, an appropriate appeal procedure must be presented to the Rail transport commission RailCom. The RailCom will determine how to proceed.

4. Overview of the calculation process

The graphic in Figure 4-1 gives an overview of the entire calculation process.

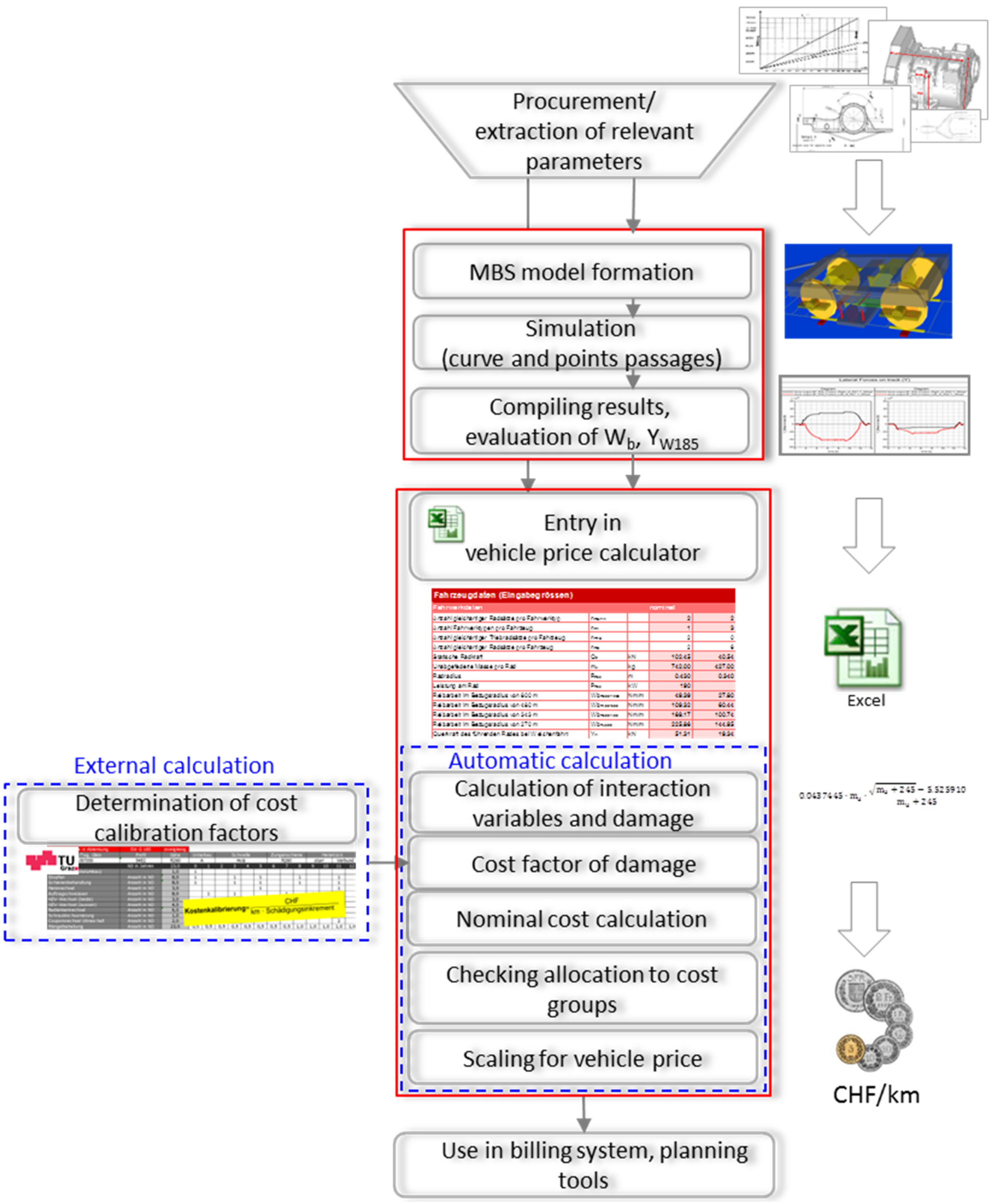


Figure 4-1: Overview of the calculation process (from the vehicle data to the price)

The first step involves deriving the relevant parameters for the calculation from the vehicle data (drawings, mass calculations, component characteristics, etc.). Certain data, such as the static vertical wheel force, the unsprung mass, the wheel radius and the power, can be entered directly in the vehicle price calculator (Excel) (Section 6.1). This calculates the interaction variables Q and the effective contact area for the T_{pv} calculation analytically (6.2).

To determine the interaction variables W_b and Y_{W185}, simulations must be performed in a piece of software for calculating multi-body systems (MBS) (e.g. SIMPACK). The necessary data is also collected and a corresponding vehicle model is produced (Section 7). The values determined for W_b and Y_{W185} are also entered in the vehicle price calculator.

The vehicle reference costs in the V/R bands are calculated automatically. The formulae used for the laws of damage and the cost calculation are described in Sections 6.3 to 6.5.

The vehicle reference costs in the radius and speed bands are subsequently (Section 8) checked for non-differentiable "type relationships" (vehicles which have very similar properties). This involves analysing whether, within the context of potential uncertainty bands for the input variables, the cost bands are sufficiently different to the costs already determined for other vehicles. If they are not sufficiently different, existing vehicle reference costs are assigned to the vehicle.

In the final step, the vehicle reference costs are multiplied by the scaling factor to calculate the definitive vehicle prices for the billing.

5. Technical principles

The following sections explain the most important principles. As these may not cover all possible special cases, please refer to the vehicle pricing department (contact details in Section 11.2) who will answer any questions in cases of doubt.

5.1. Vehicle category

The vehicles are categorised into the following 6 types:

- Locomotives
- Power cars (one-piece traction vehicle with passenger accommodation)
- Passenger cars
- Freight wagons
- Multiple units (multiple-piece traction vehicle with passenger accommodation)
- Special vehicle

Each vehicle is uniquely assigned to one type.

5.2. Loading

When determining the relevant vertical wheel force for the price calculation, the following loads are taken into account (with the exception of the freight wagons):

- Service weight with 2/3 of all operating materials
- 1/3 of seats occupied (if present) with 80 kg per seat
  (In the case of passenger cars with first-class and second-class facilities, the second class is to be taken as a basis. Folding seats do not have to be taken into account)

Five different levels of loading are generally defined for freight wagons, and a separate price calculationis carried out for each level. Table 5-1 shows the levels and the wheelset loads used for the calculation.

Loading level	Wheelset load
	[t]
#AL4_8	Empty wagon[1]
#AL8_12	10.0
#AL12_16	14.0
#AL16_20	18.0
#AL20_24	22.0

Table 5-1: Reference loads for the loading levels of freight wagons

For freight wagons where defined loads can be assumed due to their construction type or area of application (e.g. wagons from the car-carrying service or Saadkms from the lorry shuttle), the price is calculated for the empty wagon and for these specific loads.

[1] The wheelset load can vary according to the wagon type (e.g. 2-axle or 4-axle). Therefore, the actualload of the empty wagon is used.

5.3. Vehicle family

A vehicle family refers to a group of vehicles which come from the same system supplier and follow a standard philosophy (standard wagons) or have the same platform development. Vehicles in the same family feature many common parts and/or the same components.

5.4. Vehicle type

Vehicle types define a vehicle in the operational systems of the infrastructures. Before carrying out a journey, an RU must transfer the formation (the vehicle types used and their sequence) to the electronic formation service. The cost information relating to base price wear, which is relevant for the vehicle price, is also linked to the vehicle type. The vehicle type is therefore used for the train-path billing.

Individual vehicles are grouped into one vehicle type if they share the following elements in addition to belonging to the same vehicle family:

- Assignment to the vehicle category[2]
- The number of wheelsets
- The speed series
- The drive category
- The brake category

The drive categories are:
- Fully sprung drive (hollow-shaft drive)
- Partially sprung drive (axle-mounted gears)
- Unsprung drive (nose-suspension drive)

The brake categories are as follows:
- Wheels with block brakes
- Wheels with disc brakes (wheel brake discs, axle brake discs)

Furthermore, the vehicle parameters must be within the tolerances defined for vehicle families. This is determined by means of a parameter comparison (see Section 5.5).

5.5. Parameter comparison

A parameter comparison has the following objectives:

- Avoiding major organisational work when determining vehicle prices, if there are only minor differences within a vehicle fleet
- Reducing the work involved in MBS simulations: limiting the scope of modelling/eliminating the need for a simulation in the case of only limited necessity

If it can be proven that the tolerance bands for the input parameters have been adhered to, a parameter comparison allows you to adopt prices from existing vehicles of the same vehicle category. This means it is not necessary to involve an independent inspection body.

The prices of new individual vehicles cannot be determined via parameter comparisons.

[2] This results from belonging to the same vehicle family. The vehicle category continues to be used in the billingsystem.

The procedure for the cross-comparison of the vehicle relationship is based on EN 14363 [2] regarding the assessment as to whether the track test can be omitted. For the interpretation of the deviation band for parameter X, EN 14363 applies analogously:

$\Delta X_{\%} = \frac{X_{new} - X_{existing}}{X_{existing}}$ for percentage deviation,

$\Delta X_{abs} = X_{new} - X_{existing}$ for absolute deviation.

The table below shows the limits for the permissible deviations. There are different tolerances depending on whether the vehicle being assessed is a new vehicle in a vehicle family or an existing vehicle after a refit.

Parameter	Permissible tolerance	
	New vehicle in a family	Refit vehicle
Bogie distance 2a*	-20% to +10%	-
Wheelset distance 2a+	-5% to +2.5%	-
Vertical wheel force Q_0	-10% to +5%	-10% to +5%
Unsprung mass m_u	-5% to +2.5%, max. +50 kg per wheelset	-10% to +5%, max. +50 kg per wheelset
Wheelset guidance (stiffness)	-10% to +0%	-10% to +5%
Yaw damping (damping constant and blow-off force)	-100% to +25%	-100% to +25%

Table 5-2: Overview of the permissible deviations for vehicle parameters for the adoption of a vehicle price determination

5.6. Running gear type

Running gears which differ in their parameters and wheelset loads cause different types of damage. As a vehicle can have different running gear types (e.g. powered and trailer bogies), the price is calculated for each specific running gear type. The total damage is calculated by adding up the damage from all types of running gear, taking into account the number of wheelsets in each case.

Given that even similar running gears can demonstrate certain differences with regard to their descriptive parameters within a vehicle, permissible tolerances are defined. If these tolerances are adhered to, running gears which only differ in certain details can be regarded as one running gear type. This limits the scope of modelling.

Table 5-3 shows the deviations which are permitted between the parameters of similar running gears.

For all running gears of a vehicle which are to be grouped into one running gear type, the mean value is calculated for the relevant parameter. The individual values for the running gears under examination must be within the permissible limits. Any running gears with values outside the limits are regarded as a separate running gear type and are included in the calculation separately.

Parameter	Permissible deviation from mean value
Bogie distance 2a*	-20% to +10%
Wheelset distance 2a+	-5% to +2.5%
Vertical wheel force Q_0	-10% to +5%
Unsprung mass m_u	-10% to +5%, max. +50 kg per wheelset
Wheelset guidance (stiffness) c_x	-10% to +5%
Yaw damping (damping constant and blow-off force)	-100% to +25%

Table 5-3: Overview of the permissible deviations for parameters within an running gear type

Figure 5-1 shows the example of a vehicle with 6 running gears which are similar but which differ with regard to factors such as their vertical wheel force. When the mean value is calculated, it indicates that running gears 3 and 4 are outside the tolerance band. The running gears are therefore divided into two types. The mean of the individual values is taken as the key parameter. The deviations within the running gear types now adhere to the required tolerances.

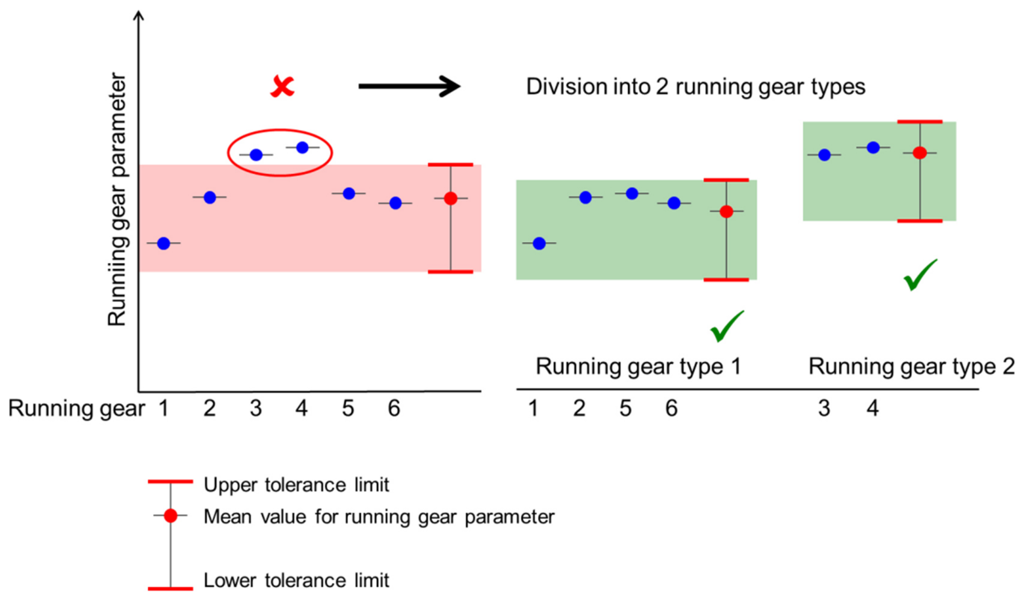


Figure 5-1: Limits of resemblance for similar running gears

5.7. Running gear frame

The running gear frame links the wheelsets to each other and to the body. On a 2-axle vehicle, the body is the running gear frame.

5.8. Wheelset relevant for damage

The basic principle is that the leading wheel of a running gear on the outside of a curve bears the damage in the respective leading wheelset, even if the forces in the running gear are redistributed due to increased free lateral acceleration.

If the running gears are of the same type, for reasons of simplicity the behaviour of the first leading wheelset is transferred to all subsequent leading wheelsets and the overall effect is taken into account based on the number (n_{FW}) in the vehicle. For a vehicle with two bogies of the same type, the behaviour of the first wheelset also applies to the leading wheelset of the second bogie (wheelset 3 on a 2-axle bogie, wheelset 4 on a 3-axle bogie, see Figure 5-2).

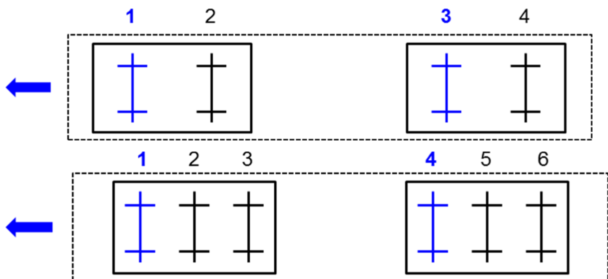


Figure 5-2: Equivalent wheelsets on a vehicle with two bogies

The similar running gear types do not need to be arranged after one another in the vehicle. In the example of a vehicle with Jakobs bogies in Figure 5-3, wheelsets 1 and 7 are equivalent – provided the running gear type is the same. The same principle applies to the Jakobs bogies. In the example, wheelsets 3 and 5 are equivalent.

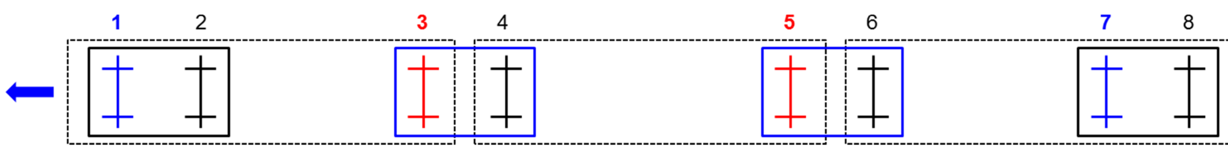


Figure 5-3: Equivalent wheelsets on a vehicle with Jakobs bogies

On multi-axle, articulated or rigid frame guides, the outer wheelsets bear the damage. In the example of the Saadkms (lorry shuttle), wheelsets 1 and 5 are equivalent.

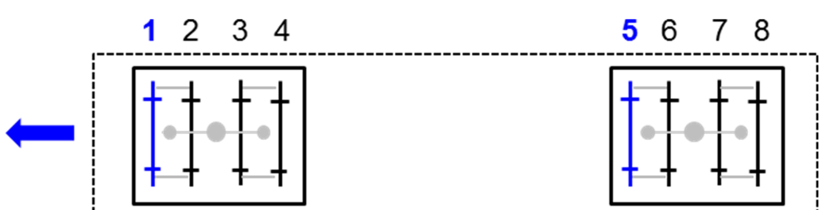


Figure 5-4: Equivalent wheelsets on a lorry shuttle wagon

With special designs, there may be uncertainty as to the classification of the wheelsets. In this case, the results of the MBS simulation must be used to decide which wheelsets can be regarded as "leading". A vehicle with a Jakobs wheelset would be an example of this kind of case.

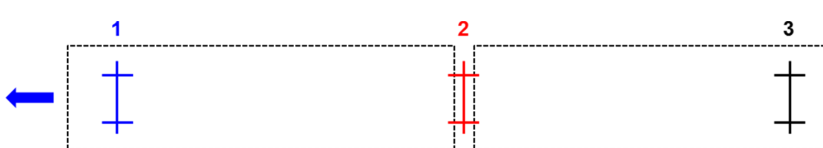


Figure 5-5: Vehicle with single and Jakobs wheelsets

6. Vehicle price calculation

A vehicle price calculator (Excel) is available at www.onestopshop.ch [9] for calculating the vehicle prices. The following sections explain the calculation in detail.

6.1. Input variables

The input variables required to calculate the vehicle prices in the V/R bands can be found in the top part of the table. The input cells have a pink background. Vehicle properties relating to mass, geometry and traction, as well as its behaviour on curves and points as determined by means of an MBS simulation (see Section 7), are to be entered. In addition, the maximum permissible speed and the maximum speed when travelling over diverting 40 km/h points must be entered as well. The vehicle category and the speed category for which the price is to be calculated are selected from a list. For vehicles which operate in multiple categories, a separate price calculation is carried out for each category.

The "Vehicle" column provides the totals for certain variables. This makes it possible to check whether all running gears and wheelsets have been included and whether the total mass and power of the vehicle are correct.

The figure below shows the data used in the example table for a multiple unit with two different running gears:

RABe 5xx 4/8				Motor Bogie	Trailer Bogie				Vehicle
Description	Formula symbol	Unit	Comment/calculation formula	Input/calculation					
Vehicle data (input variables)									
Basic data									
Vehicle category			Locomotive (Lok), power car (TWg), passenger car (PWg), freight wagon (GWg), multiple unit (TZ), special vehicle (S)						TZ
Maximum permissible speed	V_{zul}	km/h		140	140	140	140	140	140
Train category				R	R	R	R	R	R
Permissible speed on 40 km/h points	V_{Wzul}	km/h	40 km/h, if there are no restrictions	40	40	40	40	40	40
Running gear data				nominal					total
Number of similar wheelsets per running gear type	$n_{RS/FW}$			2	2				
Number of running gears for each running gear type per vehicle	n_{FW}			2	2				4
Number of similar driven wheelsets per vehicle	n_{TRS}			4	0	0	0	0	4
Number of similar wheelsets per vehicle	n_{RS}			4	4	0	0	0	8
Static vertical wheel force	Q_0	kN		75.00	50.00				101.94 t
Unsprung mass per wheel	m_u	kg		800.00	500.00				
Wheel radius (nominal value for new wheels)	R_{Rad}	m		0.450	0.400				
Maximum power at wheel	P_{Rad}	kW		150					1200
Specific frictional energy in reference radius of 270 m	$W_{b,R<300}$	Nm/m	from MBS simulation	230.00	150.00				
Specific frictional energy in reference radius of 343 m	$W_{b,R300-400}$	Nm/m	from MBS simulation	170.00	100.00				
Specific frictional energy in reference radius of 480 m	$W_{b,R400-600}$	Nm/m	from MBS simulation	100.00	60.00				
Specific frictional energy in reference radius of 800 m	$W_{b,R600-1200}$	Nm/m	from MBS simulation	50.00	25.00				
Lateral force of leading wheel when travelling over points	Y_{W185}	kN	from MBS simulation	50.00	20.00				

Figure 6-1: Input variables for the vehicle price calculation

There is a further input area for information regarding the uncertainty of the vehicle data incorporated into the calculation and MBS simulation. This information is required for calculating price limits which are used for possible assignment to an existing price group. This is explained in more detail in Section 8.

6.2. Calculating the interaction variables

In the next step, the input variables are used to calculate intermediate variables which affect the damage to the track.

6.2.1. Dynamic wheel force Q(V)

The dynamic wheel force depends on the speed, V. The following relationship applies:

$$Q(V) = a_Q \cdot V + b_Q\,, \quad \text{mit } V \ [\text{kmh}^{-1}]$$

The starting point for determining the coefficients a_Q and b_Q is the Railway Group Standard GM/TT0088 [3], whereby Q is equivalent to the P2 force defined in the Standard. All of the constants (A_z, M_z, C_z, K_z) defined in GM/TT0088 apply here:

The P2 force shall be calculated using the following formula:

$P_2 = Q + (A_z.V_m.M.C.K)$

where

$$M = \left[\frac{M_v}{M_v + M_z}\right]^{0.5}$$

$$C = 1 - \left[\frac{\pi \,.\, C_z}{4[K_z(M_v + M_z)]^{0.5}}\right]$$

$$K = \left(K_z.M_v\right)^{0.5}$$

Q = maximum static wheel load (N)

V_m = maximum normal operating speed (m/s)

M_v = effective vertical unsprung mass per wheel (kg)

A_z = 0.020 rad
(total angle of vertical ramp discontinuity)

M_z = 245 kg
(effective vertical rail mass per wheel)

$C_z = 55.4 \times 10^3$ Ns/m
(effective vertical rail damping rate per wheel)

$K_z = 62.0 \times 10^6$ N/m
(effective vertical rail stiffness per wheel)

Formula 6-1: Calculation method for P2 according to GM/TT0088 [3]

The equations and constants used in GM/TT0088 can be summarised in a formula into which the unsprung mass per wheel, m_u, and the static wheel force, Q_0, are inserted.
This produces the coefficients for the speed-dependent description of the dynamic wheel force Q(V).

$$Q(V) = Q_0 + V \cdot 0.0437445 \cdot \frac{\sqrt{m_u + 245} - 5.525910}{m_u + 245} \quad \text{in kN}$$

The coefficients a_Q and b_Q for the formula

$$Q(V) = a_Q \cdot V + b_Q\,, \quad \text{with } V \ [\text{kmh}^{-1}]$$

are therefore:

$$\mathbf{a_Q = 0.0437445 \cdot m_u \cdot \frac{\sqrt{m_u + 245} - 5.525910}{m_u + 245}}\,, \qquad \text{with } m_u \ [\text{kg}]$$

$$\mathbf{b_Q = Q_0}, \qquad \text{with } Q_0 \ [\text{kN}]$$

Formula 6-2: Calculating the coefficients for the dynamic wheel force Q(V)

6.2.1.1. Reference speeds on straight sections

Six speed bands are used to calculate prices for sections with curve radii > 1200 m. The reference speed to be applied for each band is defined in the table below:

Speed band	Reference speed
[km/h]	[km/h]
V ≤ 80	75
80 < V ≤ 100	90
100 < V ≤ 120	110
120 < V ≤ 140	130
140 < V ≤ 160	150
160 < V ≤ 200	200

Table 6-1: Reference speeds for the speed bands (R > 1200 m)

6.2.1.2. Reference speeds on curves

Radius bands are defined for sections with curve radii ≤1200 m. The reference radii for the various radius bands are calculated from the mean curvature of these bands. The reference speeds for the calculation of the dynamic wheel force depend on the speed category for which the vehicle prices are to be calculated. They are automatically calculated in the Excel table for a cant of 150 mm and are documented together with the uncompensated lateral accelerations/cant deficiencies applied in the table below:

Radius band	Reference radius	Reference speed		
		Cat. R, A, D aq 0.85 m/s² (üf 130 mm)	Cat. W aq 1.32 m/s² (üf 200 mm)	Cat. N aq 1.80 m/s² (üf 275 mm)
[m]	[m]	[km/h]	[km/h]	[km/h]
R ≤ 300	270	80.04	89.73	98.65
300 <R ≤ 400	343	90.22	101.14	111.19
400 < R ≤ 600	480	106.73	119.64	131.53
600 < R ≤ 1200	800	137.78	154.46	169.80

Table 6-2: Reference speeds for the various radius bands and speed category

The Excel table calculates the dynamic wheel force in the curve up to the maximum permissible speed for the vehicle. This means that, for a vehicle with V_{zul} = 120 km/h, the reference speed in the radius band 600 <R≤ 1200 is 120 km/h rather than 137.63 km/h.

6.2.2. Area of contact

In order to assess the influence of traction, the effective area of contact under the driven wheels is calculated. The calculation is based on Hertz's simple universal theory, as described in Dubbel [4], for example. In order to represent system-related uncertainties, however (e.g. regarding the further development of traction densities and validity of results in curves with large radii), it is multiplied by a factor of 2/3.

For the analytical calculation of the area of contact, the vehicle is assumed to be standing on a straight track (railhead radius = 300 mm). This means there is no need for special calculations of elastic penetrations for non-elliptical contacts and a tailored, sufficiently precise equation can simply be used:

The area of elliptical contact is calculated from the size of the two half-axles a and b:

$$A_{Rad} = \pi \cdot a \cdot b$$

The main curvature radii of the rail are R_{Sch} and ∞; those of the wheel are R_{Rad} and ∞.

This results in the following formula for the area calculation:

$$A_{Rad} = \pi \cdot \xi \cdot \eta \cdot \left(\frac{3 \cdot Q_0}{E^* \left(\frac{1}{R_{Sch}} + \frac{1}{R_{Rad}}\right)}\right)^{\frac{2}{3}} , \qquad \text{mit } E^* = \frac{E}{(1 - \nu^2)}$$

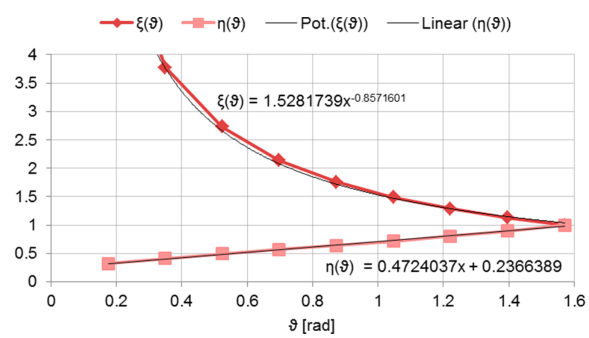
The auxiliary angle ϑ for the calculation of the coefficients ξ and η is calculated with the corresponding main curvature radii as follows:

$$\vartheta = \arccos\left(\frac{|R_{Rad} - R_{Sch}|}{R_{Rad} + R_{Sch}}\right)$$

The table values for ξ and η can be described approximately with functions:

$$\xi(\vartheta) = \frac{1.5281739}{\vartheta^{0.8571601}}$$

$$\eta(\vartheta) = 0.4724037 \cdot \vartheta + 0.2366389$$



Using the following values

$$R_{Sch} = 0.3 \text{ m}$$

$$E = 2.1 \cdot 10^{11} \frac{N}{m^2}$$

$$\nu = 0.3$$

and inserting the functions produces a calculation formula for the contact area calculation. This is then multiplied by the factor of 2/3 to be used for the T_{pv} calculation. Q_0 is entered in kN; R_{Rad} is entered in m. The area $A_{Rad,eff}$ is calculated in mm².

$$\mathbf{A_{Rad,eff}} = \frac{\mathbf{8.3593707 \cdot \vartheta + 4.1874191}}{\vartheta^{\mathbf{0.8571601}}} \cdot \left(\frac{\mathbf{Q_0}}{\frac{\mathbf{1}}{\mathbf{0.3}} + \frac{\mathbf{1}}{\mathbf{R_{Rad}}}}\right)^{\frac{\mathbf{2}}{\mathbf{3}}}$$

$$\textbf{with } \vartheta = \textbf{arccos}\frac{(|\mathbf{R_{Rad}} - \mathbf{0.3}|)}{(\mathbf{R_{Rad}} + \mathbf{0.3})}, \qquad \mathbf{Q_0}\ [\mathbf{kN}], \qquad \mathbf{R_{Rad}}\ [\mathbf{m}], \qquad \mathbf{A_{Rad,eff}}\ [\mathbf{mm^2}]$$

Formula 6-3: Analytical calculation of the reduced contact area

6.3. Calculating the damage coefficients

In the next step, the various laws of damage are applied to the interaction variables in order to calculate the damage coefficients D1 to D5.

6.3.1. Ballast damage/Track geometry loss D1= {Q^3}

The relationship D1 ~ Q^3 is regarded internationally as established knowledge [6] with regard to the connection between vertical dynamic wheel force, Q(V), and ballast damage/track geometry loss. The coefficient notation can be used to calculate the interaction variable and, hence, the damage for every speed and radius. The total damage potential is calculated by multiplying the value by the number of similar wheelsets.

For D1, every wheelset is regarded as relevant for damage.

The formula for D1 is therefore:

$$\mathbf{D1} = \mathbf{n_{RS}} \cdot \mathbf{Q(V)^3}$$

Formula 6-4: Law of damage for D1 (ballast damage and track geometry loss)

6.3.2. Rail defects on the straight track D2= {$Q^{1.2}$}

The relationship between the vertical dynamic wheel force, Q(V), and the occurrence of rolling contact fatigue due to rolling contact strain, expressed as D2 ~ $Q^{1.2}$, is an empirically determined and internationally viable variable [6]. D2 can be calculated in the same way as D1. The total damage potential is calculated by multiplying the value by the number of similar wheelsets.

For D2, every wheelset is regarded as relevant for damage.

The formula for D2 is therefore:

$$\mathbf{D2} = \mathbf{n_{RS}} \cdot \mathbf{Q(V)^{1.2}}$$

Formula 6-5: Law of damage for D2 (rail defects on straight track)

6.3.3. Rail defects on the straight track due to drive, D3= {T_{pv}}

Based on experience, the traction power value (T_{pv}) can be regarded as an indication of drive-induced rolling contact fatigue [6] under the driven wheel. In the foreground is the power density which is transferred by the contact patch (total contact area for all driven wheels) with the maximal installed power of the vehicle. No effective traction forces or similar values are applied. The total damage potential for a wheel and a vehicle remains the same, so there is no need to multiply the value by the damage-related wheelsets.

The formula for D3 is:

$$D3 = \alpha \cdot T_{pv} = \alpha \cdot \frac{P_{Rad}}{A_{Rad,eff}}$$

The utilisation coefficient α has a value of 1 for the time being. In a subsequent refinement of the calculation, this coefficient enables the power utilisation to be taken into account – if, for example, the same vehicle operates in the IR or S-Bahn network. For the current calculation of D3, the following therefore applies:

$$\mathbf{D3 = T_{pv} = \frac{P_{Rad}}{A_{Rad,eff}}}\ , \quad \textbf{with} \quad \mathbf{P_{Rad}\ [kW],\ A_{Rad,eff}\ [mm^2]}$$

Formula 6-6: Law of damage for D3 (rail defects on straight track due to drive)

6.3.4. Rail defects and rail wear on curved track, D4.1, D4.2 = {W_b}

Based on experience, the frictional energy exerted during wheel/rail contact is proven to trigger rolling contact fatigue D4.1 (head checking) or wear D4.2 on the curve [6], [6]. The specific frictional energy determined by means of MBS simulations (see Section 7) is divided into wear, rolling contact fatigue or hybrid forms by an evaluative function.

The total damage potential is calculated by multiplying the value by the total number of leading wheel-sets on a common running gear frame, as it is only these wheelsets that are relevant for damage.

The formulae for D4.1 and D4.2 are as follows:

$$\mathbf{D4.1 = 0\ ,} \qquad \textbf{for } \mathbf{W_b < 15\ Nm/m}\ \textbf{und}\ \mathbf{W_b \geq 175\ Nm/m}$$

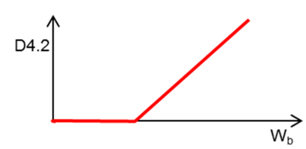
$$\mathbf{D4.1 = n_{FW} \cdot (0.02 \cdot W_b - 0.3)} \qquad \textbf{for } \mathbf{15\ Nm/m \leq W_b < 65\ Nm/m}$$

$$\mathbf{D4.1 = n_{FW} \cdot (-W_b + 175)/110} \qquad \textbf{for } \mathbf{65\ Nm/m \leq W_b < 175\ Nm/m}$$

Formula 6-7: Law of damage for D4.1 (rolling contact fatigue on a curve)

$$\mathbf{D4.2 = 0\ ,} \qquad \textbf{for } \mathbf{W_b < 65\ Nm/m}$$

$$\mathbf{D4.2 = n_{FW} \cdot \frac{W_b - 65}{110}} \qquad \textbf{for } \mathbf{W_b \geq 65\ Nm/m}$$



Formula 6-8: Law of damage for D4.2 (wear on a curve)

6.3.5. Points degradation due to vertical and horizontal forces, D5 = {$Q_{W185}^2 + Y_{W185}^2$}$^{0.5}$

The combined strains on the points, composed of horizontal (Y) and vertical forces (Q), serve as an indication of the loads on points components [6].

The lateral force, Y_{w185}, of the leading wheel on the outside of the curve is determined from the MBS simulation of a journey along a 185 m S-shaped curve (see Section 7).

The vertical force, Q_{W185}, is determined for the maximum permissible speed, V_{Wzul}, for travelling over diverting 40 km/h points (generally 40 km/h) from the coefficients of the interaction variable Q ($Q_{W185} = Q(V_{Wzul})$).

The total damage potential is calculated by multiplying D5 by the total number of leading wheelsets on a common running gear frame. These are the wheelsets that are relevant for damage.
The formula for D5 is:

$$\mathrm{D5} = \mathrm{n_{FW}} \cdot \sqrt{\mathrm{f5_1} \cdot \mathrm{Q(V_{Wzul})^2} + \mathrm{f5_2} \cdot \mathrm{Y_{W185}}^2}$$

The factors $f5_1, f5_2$ enable different damage weightings; they are currently set as 0.5

$$\mathbf{D5} = \mathbf{n_{FW}} \cdot \sqrt{\mathbf{0.5} \cdot \mathbf{Q(V_{Wzul})^2} + \mathbf{0.5} \cdot \mathbf{Y_{W185}}^2}$$

Formula 6-9: Law of damage for D5 (points damage)

6.3.6. Total damage potential for the vehicle

The damage coefficients D1 to D5 are calculated for each running gear type of the vehicle. The total damage potential for the various speed and radius bands is calculated for the overall vehicle (with the exception of D3) by adding up the damage coefficients for all running gear types (column O in the Excel calculation table).

$\boldsymbol{D_{j,/R-Band,total}} = \sum_k \boldsymbol{D_{j,V/R-Band,k}}$, with j: 1, 2, 4.1, 4.2, 5, k: Index of the running gear type

Formula 6-10: Calculation of the total damage (D1, D2, D4.1, D4.2, D5) for each band

If the vehicle has running gears that are driven in different ways, resulting in multiple values for D3 (T_{pv}), the total value is calculated by means of an averaging process which takes into account the respective number of driven wheelsets, n_{TRS}.

$\mathbf{T}_{pv,total} = \frac{\sum_k (n_{TRSk} \cdot \mathrm{T}_{pv,k})}{\sum_i n_{TRSk}}$, with k: Index of the running gear type

Formula 6-11: Calculation of the total value for T_{pv} (= D3)

6.4. Cost calibration factors

Each type of damage (D1 to D5) is assigned a type of maintenance work and the associated work and repair costs (cf. Section 2, Figure 2-1). These are strategic costs for damage repair or costs for preventative measures. Please refer to [6] to determine the cost calibration factors (k1 to k5). The cost calibration factors (column AE in the Excel vehicle price calculator) are summarised in the following table:

Band	Cost calibration factors					
	k1	k2	k3	k4.1	k4.2	k5
straight track	0.000000000883	0.000002818560	0.003379926726	0	0	0.000234518869
R<300	0.000000010785	0	0	0.081359599719	0.058656594313	0.000234518869
R300-400	0.000000002667	0	0	0.010953481857	0.023825333808	0.000234518869
R400-600	0.000000001556	0	0	0.010953481857	0.023825333808	0.000234518869
R600-1200	0.000000000949	0	0	0.010953481857	0	0.000234518869

Table 6-3: Overview of cost calibration factors

6.5. Calculating the vehicle prices

To calculate the vehicle reference costs, the total damage – D1 to D5 – is multiplied by the respective cost calibration factors k1 to k5 (column AC in the Excel calculation table) and then added up for each band (see Figure 6-2).

No prices are calculated for speed bands on straight sections which exceed the permissible speed of the vehicle.

The vehicle reference costs are then multiplied by the scaling factor (see Section 2.1). This produces the definitive vehicle prices for the train-path price billing.

Calculation of vehicle reference costs

			summands						nominal
T_{pv}	$Crel_{Tpv}$	CHF/km			k.D3				0.0074883
V0-80	$Crel_{V0-80}$	CHF/km	$k.D1_{V0-80}$	$k.D2_{V0-80}$	k.D3			k.D5	**0.0943495**
V80-100	$Crel_{V80-100}$	CHF/km	$k.D1_{V80-100}$	$k.D2_{V80-100}$	k.D3			k.D5	**0.0994179**
V100-120	$Crel_{V100-120}$	CHF/km	$k.D1_{V100-120}$	$k.D2_{V100-120}$	k.D3			k.D5	**0.1074675**
V120-140	$Crel_{V120-140}$	CHF/km	$k.D1_{V120-140}$	$k.D2_{V120-140}$	k.D3			k.D5	**0.1171442**
V140-160	$Crel_{V140-160}$	CHF/km	$k.D1_{V140-160}$	$k.D2_{V140-160}$	k.D3			k.D5	
V>160	$Crel_{V>160}$	CHF/km	$k.D1_{V<200}$	$k.D2_{V<200}$	k.D3			k.D5	
R<300	$Crel_{R<300}$	CHF/km	$k.D1_{R<300}$			$k.D4.1_{R<300}$	$k.D4.2_{R<300}$	k.D5	**0.5511231**
R300-400	$Crel_{R300-400}$	CHF/km	$k.D1_{R300-400}$			$k.D4.1_{R300-400}$	$k.D4.2_{R300-400}$	k.D5	**0.1966341**
R400-600	$Crel_{R400-600}$	CHF/km	$k.D1_{R400-600}$			$k.D4.1_{R400-600}$	$k.D4.2_{R400-600}$	k.D5	**0.1573680**
R600-1200	$Crel_{R600-1200}$	CHF/km	$k.D1_{R600-1200}$			$k.D4.1_{R600-1200}$		k.D5	**0.1257581**

Conversion to vehicle prices

Scaling factor	**S**			2.35

Calculation of vehicle prices

				nominal
T_{pv}	C_{Tpv}	CHF/km	$Crel_{Tpv}$ * S	0.0175975
V0-80	C_{V0-80}	CHF/km	$Crel_{V0-80}$ * S	**0.2217213**
V80-100	$C_{V80-100}$	CHF/km	$Crel_{V80-100}$ * S	**0.2336321**
V100-120	$C_{V100-120}$	CHF/km	$Crel_{V100-120}$ * S	**0.2525486**
V120-140	$C_{V120-140}$	CHF/km	$Crel_{V120-140}$ * S	**0.2752889**
V140-160	$C_{V140-160}$	CHF/km	$Crel_{V140-160}$ * S	
V>160	$C_{V>160}$	CHF/km	$Crel_{V160-200}$ * S	
R<300	$C_{R<300}$	CHF/km	$Crel_{R1-300}$ * S	**1.2951393**
R300-400	$C_{R300-400}$	CHF/km	$Crel_{R300-400}$ * S	**0.4620901**
R400-600	$C_{R400-600}$	CHF/km	$Crel_{R400-600}$ * S	**0.3698148**
R600-1200	$C_{R600-1200}$	CHF/km	$Crel_{R600-1200}$ * S	**0.2955315**

Figure 6-2: Vehicle reference costs and vehicle prices for the sample vehicle in the Excel vehicle price calculator

The first row of the vehicle price table lists the price C_{Tpv} resulting from the T_{pv} separately. This price is the summary component of the vehicle prices on straight sections. Displaying it separately enables a refund for the train-path price for towed vehicles in the billing system.

If looking into group cost formation (see Section 8) does not result in any other price allocation, these are the vehicle prices that apply to the vehicle.

7. Multi-body simulation

The following sections describe how to perform multi-body simulations, which are necessary in order to determine the specific frictional energy, W_b, and the guiding force on points, Y_{W185}, which are to be entered in the Excel calculation (see Section 6.1).

7.1. Multi-body model

7.1.1. Modelling

In order to calculate the necessary variables, the vehicle must be modelled in such a way as to map the properties that are relevant to the train-path price. A model created for the purpose of verification calculations relating to running generally fulfils these requirements. In some cases, the loading condition may need to be adjusted.

For vehicles with tilting technology or rolling compensation, the active control equipment does not need to be taken into account in the simulations.

7.1.2. Weight/Vertical wheel force

The model corresponds to the loading defined in Section 5.2 and exhibits the vertical wheel force (mean value for left and right wheel) used in the price calculation (Section 6.1) for the wheelsets under examination (with a tolerance of 1%).

7.1.3. Track model

An elastically supported track is modelled with parameters according to ERRI B176 [5].

Figure 7-1 shows the values which are used as standard when using the elastic track model.

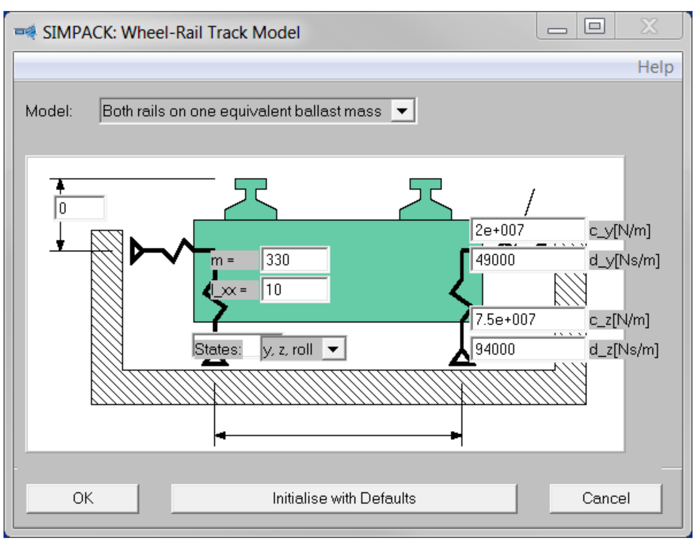


Figure 7-1: Modelling the elastic track (e.g. in SIMPACK 8.9)

7.1.4. Wheel/rail contact

The modelling of the wheel/rail contact can vary depending on the simulation software used. It must correspond to the state of the art. The elliptical as well as non-elliptical wheel-rail contact used in SIMPACK by Dassault Systèmes[3] can be considered as a reference.

The following boundary conditions for the wheel/rail contact apply to all simulations.

7.1.4.1. Wheel and rail profile

The current standard profile combination in Switzerland is the wheel profile
EN 13715 – **S 1002** / **e32.5** with the rail profile EN 13674 – **60E1** (with inclination 1:40). To ensure that the same boundary conditions apply to all vehicles, the simulations are always performed with this profile pairing (theoretical new profiles).

7.1.4.2. Track gauge and distance between active faces of wheelsets

The distance between the active faces of the wheelsets is 1425 mm. The nominal dimension of 1435 mm is used for the track gauge (gauge widening on curves R≤275 m is disregarded).

7.1.4.3. Friction coefficient

A friction coefficient of 0.3 is set between the wheel and the rail (constant over the entire profile).

7.2. Simulations

A sample rate of 100 Hz or more is to be used for the simulations.

7.2.1. Simulations to determine the specific frictional energy, W_b

7.2.1.1. Path layout

The calculations are carried out for various curve radii. In order to determine the specific frictional energy in the reference radii (see Table 6-2), the simulation must be performed in these curve radii (270 m, 343 m, 480 m and 800 m). To give a better indication of the development of the frictional energy in relation to the curve radius, it is also calculated for the radii which form the limits of the four bands: 250 m, 300 m, 400 m, 600 m and 1200 m.

The train is simulated as travelling around curves to the right and to the left with a cant of 150 mm.

Path layout files are available for calculations with SIMPACK (*track_cartographic/SBB_S-Curve_R250_u150.trc*, etc.). The two curves are summarised in one path layout. They are separated by an intermediate straight section and each curve has a straight section at the start and end. The diagram in Figure 7-2 shows the progression.

The straight section at the start has a minimum length of 200 m. The constant curves always have a length of 600 m each. The intermediate straight section between the left and right curves has a length

[3] www.simpack.com

of at least 100 m, as does the straight section at the end of the path layout. The lengths of the transition curves and cant ramps vary depending on the curve radius.

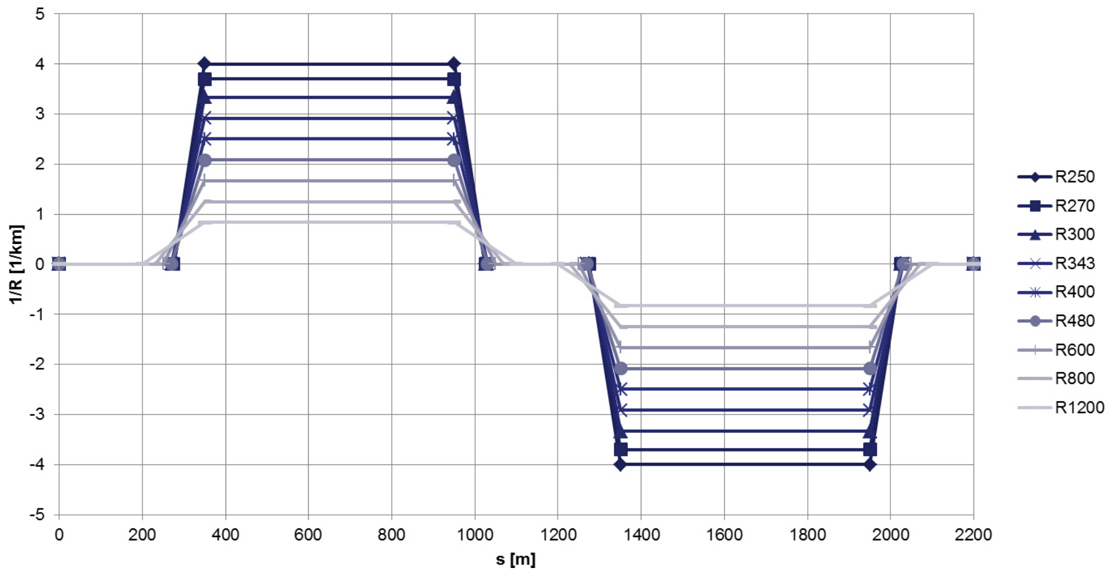


Figure 7-2: Curvature progressions for the proposed path layouts

The table below documents the properties of the individual path layout sections in detail.

Curve radius			**Section lengths**		
	Start	Transition	Full curve	Intermediate straight section	End
[m]	[m]	[m]	[m]	[m]	[m]
250	275	75	600	250	175.0
270	275	75	600	250	175.0
300	275	75	600	250	175.0
343	270	80	600	240	170.0
400	270	80	600	240	170.0
480	270	80	600	240	170.0
600	250	100	600	200	150.0
800	230	120	600	160	130.0
1200	200	150	600	100	100.0

Table 7-1: Section lengths for path layout elements

7.2.1.2. Track geometry disruption

Track geometry disruption is used in the simulation of the vehicle travelling around the curves. This disruption is defined in the template (*track_excitated/SBB_TrackExcitation_2000m.tre*) in the SIMPACK format as track-related disruption and has the following sign definitions:

Alignment (lateral excitation): Positive to the right
Longitudinal level (vertical excitation): Positive downwards
Cross level (excitation around the x-axis): Positive in a clockwise direction
Change to track gauge: Not relevant as constant zero

The track geometry starts after 200 m and has a fade-in and fade-out length of 20 m.

A summary of the path layout file and track geometry disruption can also be found in the template in a track database file (e.g. *mbs_db_track/SBB_S-Curve_R250_u150_excitated.sys*).

7.2.1.3. Speed/Traction

The simulations are performed at a constant speed without exerting drive torques on the wheelsets.

For the various curve radii, there are particular specifications regarding the uncompensated lateral acceleration (aq), and therefore the speed, depending on the train category (R, A, D, W, N) for which the vehicle is homologated (see also 6.2.1.2). These specifications are listed in Table 6-2.

The maximum speed used for the simulations is the maximum permissible speed for the vehicle; i.e., in a deviation from Table 6-2, a vehicle from series A with a maximum speed of 120 km/h will only travel along the 800 m and 1200 m curves in the simulation at 120 km/h.

If the vehicle operates in multiple train categories, the simulations are performed for all relevant series.

Radius band	Radius Reference radius	**Speed** Cat. R, A, D aq 0.85 m/s², (üf 130 mm)	Cat. W aq 1.32 m/s², (üf 200 mm)	Cat. N aq 1.80 m/s², (üf 275 mm)
[m]	[m]	[km/h]	[km/h]	[km/h]
R≤300	250	77.02	86.34	94.92
	270	80.04	89.73	98.65
	300	84.37	94.58	103.98
300<R≤400	343	90.22	101.14	111.19
	400	97.43	109.22	120.07
400<R≤600	480	106.73	119.64	131.53
	600	119.32	133.76	147.05
600<R≤1200	800	137.78	154.46	169.80
	1200	168.75	189.17	207.97

Table 7-2: Reference speeds for the various radius bands and train categories

7.2.2. Simulation to determine the lateral force on points, Y_{W185}

7.2.2.1. Path layout

The calculation is carried out on an S-shaped curve with radii of 185 m without transition curves or a cant, and with an intermediate straight section of 6 m. This is a typical case for a points connection. A path layout of this nature is also used for tests to evaluate the vehicle behaviour on points according to Annex F of the EN14363:2016 [2].

A path layout file (*track_cartographic/SBB_S-Curve_Switch_R185_u000.trc*) and a track database file (*mbs_db_track/SBB_S-Curve_Switch_R185_u000.sys)* are provided for calculations with SIMPACK.

The straight section at the start has a length of 200 m and is connected to a right-hand curve with a length of 20.5 m. After an intermediate straight section of 6 m there is a left-hand curve which also has a length of 20.5 m. The path layout ends with a 100-m-long straight section. The diagram below shows the progression.

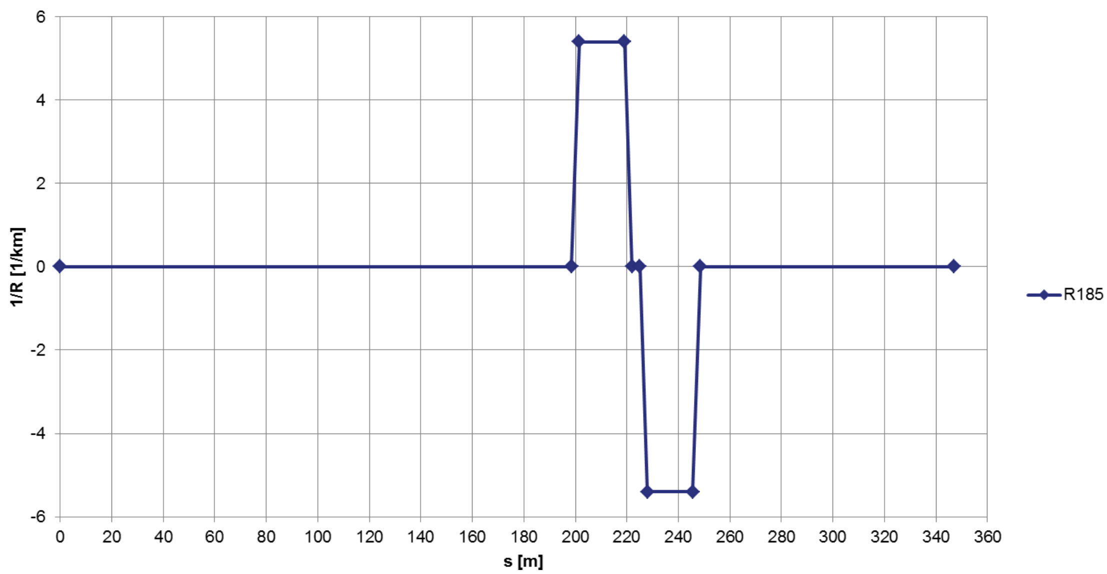


Figure 7-3: Curvature progression for the points path layout

The path layout does not model transition curves. The transition between straight and curved sections is formed in SIMPACK by means of a "smoothing section", for which a half-length of 1.5 m is selected.

7.2.2.2. Track geometry disruption

No track geometry disruption is taken into account.

7.2.2.3. Speed/Traction

The simulations are performed at a constant speed of 40 km/h without exerting drive torques on the wheelsets.

If the vehicle has a specified operational speed limit when travelling over points (e.g. max. 30 km/h), this reduced speed can be used.

7.2.3. SIMPACK templates

The table below shows the files related to this document.

Folder	File name	Description
track_cartographic	SBB_S-Curve_R250_u150.trc SBB_S-Curve_R270_u150.trc SBB_S-Curve_R300_u150.trc SBB_S-Curve_R343_u150.trc SBB_S-Curve_R400_u150.trc SBB_S-Curve_R480_u150.trc SBB_S-Curve_R600_u150.trc SBB_S-Curve_R800_u150.trc SBB_S-Curve_R1200_u150.trc	Path layout data for the simulations to determine the specific frictional energy, W_b
track_cartographic	SBB_S-Curve_Switch_R185_u000.trc	Path layout file for the simulation to determine the lateral force on points, Y_{W185}
track_excitated	SBB_TrackExcitation_2000m.tre	Track geometry disruption for all simulations except travelling over points
mbs_db_track	SBB_S-Curve_R250_u150_excitated.sys SBB_S-Curve_R270_u150_excitated.sys SBB_S-Curve_R300_u150_excitated.sys SBB_S-Curve_R343_u150_excitated.sys SBB_S-Curve_R400_u150_excitated.sys SBB_S-Curve_R480_u150_excitated.sys SBB_S-Curve_R600_u150_excitated.sys SBB_S-Curve_R800_u150_excitated.sys SBB_S-Curve_R1200_u150_excitated.sys	SIMPACK "Track DataBase File" for the simulations to determine the specific frictional energy, W_b (path layout and track geometry disruption)
mbs_db_track	SBB_S-Curve_Switch_R185_u000.sys	SIMPACK "Track DataBase File" for the simulation to determine the lateral force on points, Y_{W185}

Table 7-3: List of SIMPACK templates

The files are text files which can be used directly for simulations with SIMPACK. In other simulation programs, the path layouts and the track geometry must be implemented according to the templates. The same applies if a different track description is desired in SIMPACK.

If the vehicle model requires different lengths at the beginning and end of the path layout compared to the templates, they can be adapted as necessary. The changes must be taken into account in the evaluations.

7.3. Evaluation

7.3.1. Evaluation of the specific frictional energy, W_b

The specific frictional energy, W_b, (also referred to as Tγ in the references) is the product of the slip forces T and slips v in the wheel/rail contact and has the unit Nm/m. The calculation is made according to the formula: $Wb = |Txvx|+|Tyvy|$. Drilling torque and drilling slip are not taken into account, as the calculation is not available in all contact models. Thus, a comparability of the calculations is possible.

The specific frictional energy is evaluated without filtering in the ranges of the full curves. For the right-hand curve, the section from 400 to 900 m is examined; for the left-hand curve, it is the section from 1400 to 1900 m (when using the path layout described in Section 7.2.1.1). The mean value for the wheel on the outside of the curve is determined for each section.

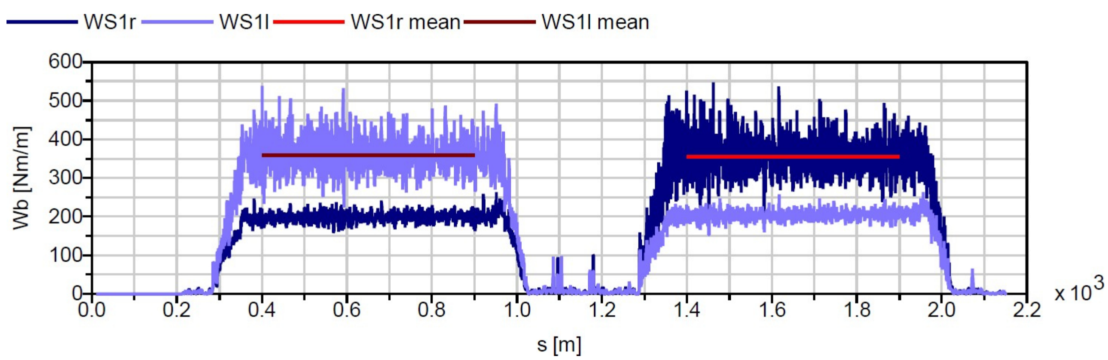


Figure 7-4: Plotted result of a simulation for the evaluation of W_b

The mean value is calculated from the two values for the right-hand and left-hand curves. This means that the 9 simulation calculations result in 9 values for W_b for each relevant wheelset. These values are documented in a results table and are shown in a diagram in relation to the curve radius (Figure 7-5).

The vehicle price calculation requires W_b values for the reference radii of 270, 343, 480 and 800 m (shown in red in Figure 7-5). The results for the other curve radii are used for checking. In the case of normal vehicle behaviour, the W_b values for the reference radii are roughly between the values calculated for the respective band limit radii (e.g. $W_{b,R270} \approx (W_{b,R250}+W_{b,R300})/2$). If this is the case, the W_b values for the reference radii are used directly for the price calculation.

If the mean value for the W_b values of the limit radii differs significantly from the value calculated for the reference radius, the results are analysed in more detail and a plausible W_b value is determined for the relevant radius band. This might be the case for running gear designs where special elements influence the radial adjustment of the wheelsets depending on the curve radius, resulting in discontinuities in the Wb function. It may be necessary to perform additional simulations with further curve radii in order to examine special behaviour of this nature in more detail.

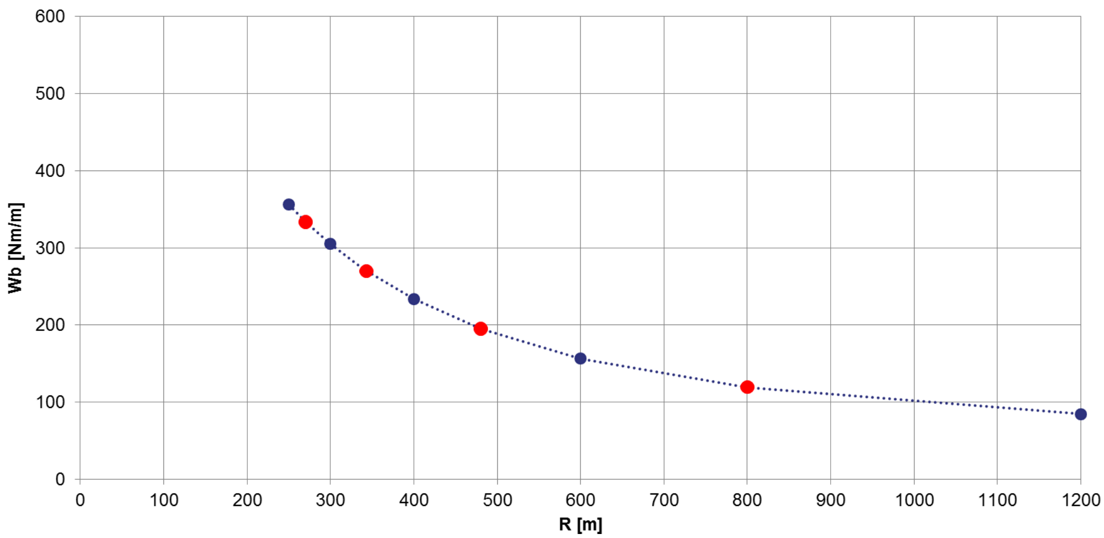


Figure 7-5: Results for W_b for various curve radii (reference radii shown in red)

If necessary, the values can be used to approximate the W_b progression by means of a suitable function. If, in the future, the price calculation requires a different breakdown of the radius bands, new values can be calculated for other reference radii using the function.

7.3.2. Evaluation of the lateral force on points, Y_{W185}

To determine Y_{W185}, the Y-forces of the leading wheelset are evaluated. To do this, the forces are filtered using the sliding mean method with a window of 2.0 m and a step of 0.5 m. Figure 7-6 shows the progression of the forces for the right and left wheels of the leading wheelset. The absolute maximum value is determined for both wheels. Y_{W185} is the larger of the two values.

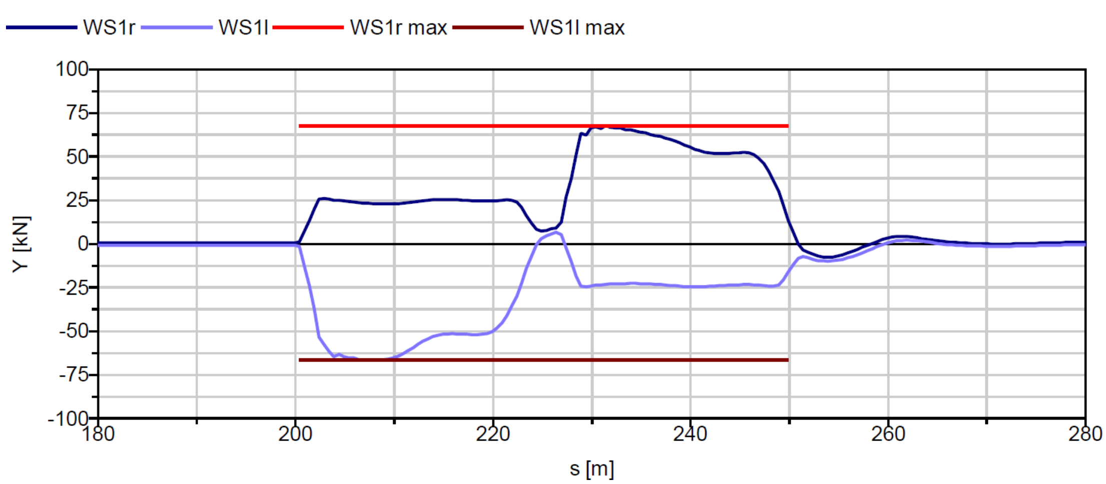


Figure 7-6: Plotted result of a simulation for the evaluation of Y_{W185}

7.4. Documenting the multi-body simulations

7.4.1. Model description

The model description specifies the MBS software used (including the version) and explains the MBS model. If the calculations are not carried out with SIMPACK, it may be necessary to describe the program and – in particular – the modelling of the wheel/rail contact that it uses in more detail. It must be proven that the software used corresponds to the state of the art with regard to the simulation of railway vehicles (e.g. by means of benchmark simulations).

Also when using SIMPACK, the selected settings for the wheel-rail contact are documented (e.g. 'equivalent elastic' or 'discrete elastic') and justified if necessary.

The modelling depth is described with regard to the model. Explanations are provided if model-related simplifications are carried out; for example, by grouping elements and determining equivalent stiffness. In particular, special features of the wheelset guidance, such as navigators, cross anchors, etc., are described. The modelling of mechatronic elements (e.g. for body tilt or running gear control) is also addressed.

7.4.2. Model parameter data set

The model parameter data set describes all elements used in the model together with their parameters. It should be possible to use this description for remodelling. The simulation results of the model can be used to verify the calculated values.

An example of this kind of data set can be found in the Annex (Section 12).

7.4.3. Calculation report

The calculation report documents the vertical wheel forces of the model (see 7.1.2) and compares them with theresults of the weighing log. In the case of vehicles for which a load is to be taken into account, the weight is compared with that of a model of the empty vehicle. The vertical wheel forces of both the empty and loaded vehicles are documented.

The plausibility of the model is checked by means of an eigenvalue analysis. The eigenvalues (frequencies and Lehr's damping) are documented up to 20 Hz.

If the path layout has been adapted in the train-path-price-specific simulations (Section 7.2), this is explained.

The results of the simulations are represented in diagrams which can be found in Section 7.3. The following representations of results are expected:

- Plotted results for the relevant leading wheelsets:
  - $W_b(s)$ (similar to Figure 7-4)
  - $Y_{W185}(s)$ (similar to Figure 7-6)
- Representation of $W_b(R)$ (similar to Figure 7-5)
- Table summarising W_b results

The report contains information about the people involved in the calculation:

- Name
- Contact data
- Qualifications (see also Section 3.3.1.1)
- Project references

7.4.4. Result files

The results of all simulations are provided digitally as ASCII data, SIMPACK sbr or MATLAB mat files. The simulated variables which are included in the results without filtering are listed in Table 7-4.

Simulation variable	Notation	Unit
Global variables		
Time coordinates	t	s
Distance coordinates	s	m
Relative speed	vrel	m/s
Wheel/rail variables (for all wheelsets)		
Angle of attack	alpha	rad
Vertical force	Q	N
Lateral force	Y	N
Lateral/vertical force	Y/Q	-
Longitudinal slip force	Tx	N
Lateral slip force	Ty	N
Longitudinal slip	nux	-
Lateral slip	nuy	-
Accelerations		
Lateral acceleration at track level	aq	m/s^2
Lateral acceleration in the body above the running gear	ay	m/s^2
Vertical acceleration in the body above the running gear	az	m/s^2

Table 7-4: List of simulation variables in the result files

If different notations or units are used, this is documented accordingly in the calculation report, for example.

8. Group cost calculation

8.1. Background and principles

8.1.1. Uncertainty regarding the vehicle data

The cost calculation requires knowledge of the vehicle parameters. However, this is not available with the same level of quality for every vehicle. In the case of older existing vehicles in particular, the input data may be less reliable due to gaps in the documentation of the vehicle parameters required for the calculation. A qualified estimate is therefore often used for the data. The younger the vehicles are, the less of an issue they pose with regard to the state of the documentation. Vehicle manufacturers will have the best access to the data for their vehicles. Over the years of operation, however, some variables may deviate from the original manufacturer information. Replacing components, for example, may change the service weight.

The following parameters are subject to the greatest uncertainty/have the greatest influence on the cost calculation and special attention must therefore be paid to their reliability:

- Vehicle mass (service weight)
- Unsprung mass
- Longitudinal stiffness of the wheelset guidance
- Yaw damping
- Mass moment of inertia of the running gear about the vertical axis
- Frictional values of components subject to friction

Groups of vehicles with the same costs are formed if their vehicle reference costs are close to each other in all speed and radius bands. This procedure assumes it is not possible to completely rule out the eventuality that the minor cost differences are due to the uncertainty of/fluctuations in the input parameters rather than having technical causes.

8.1.2. Consequences of data uncertainty for the cost calculation

The effect of changing the vertical wheel force, Q_0, and the unsprung mass, m_u, on the costs can be traced directly in the analytical calculations. For the variables which are determined from the MBS simulation, the effect of a parameter change on W_b and Y_{W185} has been determined based on reference vehicles and selected simulations. If a parameter change leads to a reduction in damage, this will result in the factors for the input variables listed in Table 8-1 .

The total factors for W_b and Y_{W185} are calculated by multiplying the relevant sub-factors. This assumes that, when estimating the nominal values of all influencing parameters, an error has been made to the disadvantage of the vehicle. Multiplying the input variables with the factors changes the input variables such that a new cost calculation produces a lower limit for the vehicle reference costs of the vehicle.

The same procedure is used to determine an upper limit for the vehicle reference costs. The factor for the upper limit is symmetrical to 1 and is calculated with the formula $f_o = 2 – f_u$ (e.g. the upper factor for Q_0 with 2.5% deviation is 2 – 0.975 = 1.025).

This upper limit was used to form cost groups in which similar vehicles were grouped together.

Influencing parameter		Factors for the input variables			
		Q_0	m_u	W_b	Y_{W185}
Service weight deviation					
- No series differences, new build	1.0%	0.99000		0.99236	0.99500
- Old vehicles with refits	2.5%	0.97500		0.98090	0.98750
- Old vehicles with refits, different RUs	5.0%	0.95000		0.96180	0.97500
Uncertainty of unsprung mass					
- Trailing wheelset, block brakes	0%		1.00000		
- Trailing wheelset, disc brakes	5%		0.95000		
- Drive, fully sprung	8%		0.92000		
- Drive, partially sprung/unsprung	15%		0.85000		
Longitudinal stiffness of the wheelset guidance					
- $c_x \geq 30$ kN/mm				0.98000	1.00000
- 15 kN/mm $\leq c_x <$ 30 kN/mm				0.97900	1.00000
- 8 kN/mm $\leq c_x <$ 15 kN/mm				0.93200	1.00000
- $c_x <$ 8 kN/mm				0.88700	0.99200
Yaw damping					
- No yaw damper or characteristic known precisely					1.00000
- Characteristic estimated					0.97400
Mass moment of inertia of the running gear about the vertical axis					
- Exact data from CAD					0.98860
- Data estimated					0.98340
Frictional value of the frictional elements					
- No frictional elements				1.00000	1.00000
- $\mu < 0.08$				0.97000	0.95730
- $0.08 \leq \mu < 0.15$				0.94700	0.92980
- $\mu \geq 0.15$				0.91600	0.90720

Table 8-1: Matrix for the factors of the input variables for the calculation of the lower vehicle cost limit

8.1.3. Initialising group costs for the base price wear with existing vehicles

The following principles apply to vehicles in a cost group:

- The vehicle category (see Section 5.1) is the same
- The number of wheelsets is the same
- The speed category and the maximum speed are the same
- The damage behaviour, and therefore the vehicle reference costs, are similar in all speed and radius bands

When the costs were determined for the existing vehicles, vehicles which met these criteria were analysed with regard to their lower and upper vehicle reference cost limits. They were assigned new reference costs if their nominal costs were within the limits of the upper and lower costs for a different vehicle in all 10 speed and radius bands.

Figure 8-1 illustrates the procedure: The nominal costs of vehicle B are within the cost limits of vehicle A and the nominal costs of vehicle D are within the limits of vehicle B. This is shown in bands 1 (V0-80) and 2 (V80-100) by way of example and is also the case in all other bands. In the case of vehicles E and F, their nominal costs are only within the limits of the other vehicle in band 1. For band 2, the condition is not fulfilled. Vehicle C does not overlap at all with other vehicles.

The new group costs are the respective mean values, weighted for train kilometres, for the individual vehicle reference costs. The group costs are only fixed for existing vehicles and are not subject to further changes if new vehicles are added.

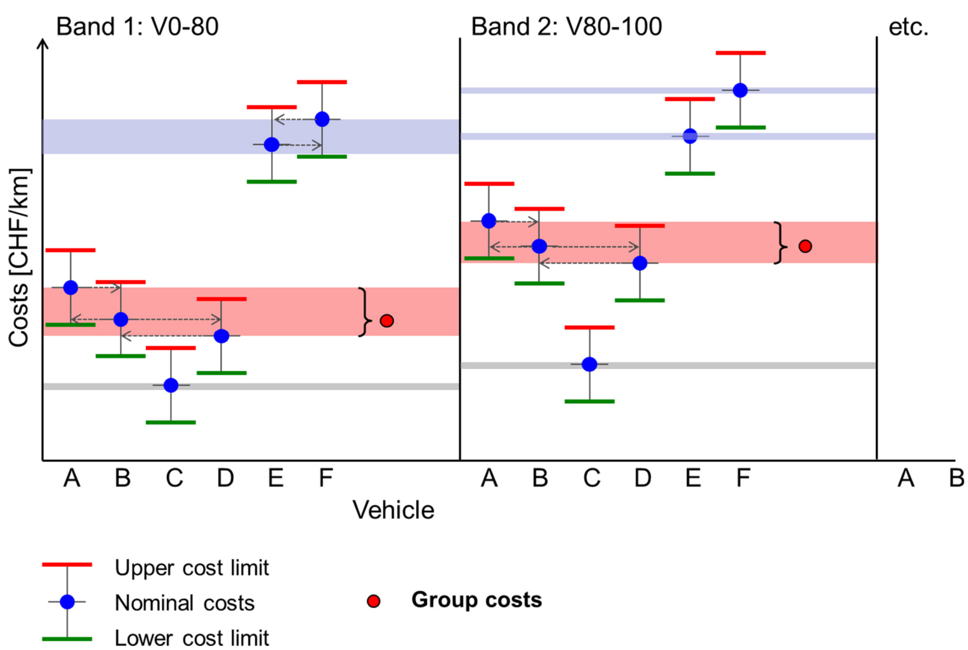


Figure 8-1: Rule for determining group costs

8.1.4. Cost group allocation for new vehicles

When the vehicle reference costs are being newly calculated for a vehicle, it is possible to adopt the reference costs from an existing vehicle. Unlike in the case of the initial group costs, the upper and lower cost limits of the existing vehicles are not published in live operation. This simplifies the process for the cost consolidation check because it only involves the parameters of the new vehicle.

If the first two principles for cost groups (same vehicle category and same number of wheelsets) are fulfilled, a check is carried out to verify whether the reference costs of an existing vehicle are within the cost range of 50% of the upper and 100% of the lower cost limit for the vehicle to be evaluated. If this is the case in all 10 bands, the new vehicle adopts the costs of the existing vehicle.

In the example in Figure 8-2, the costs of vehicles B and D are between the 50% value for the upper limit and the full lower limit of the new vehicle in band 1. In band 2, this is the case for vehicles A and D. The condition is therefore only fulfilled in both bands by the costs of vehicle D. Provided that this is also the case in the other bands, the new vehicle is allocated the costs of vehicle D.

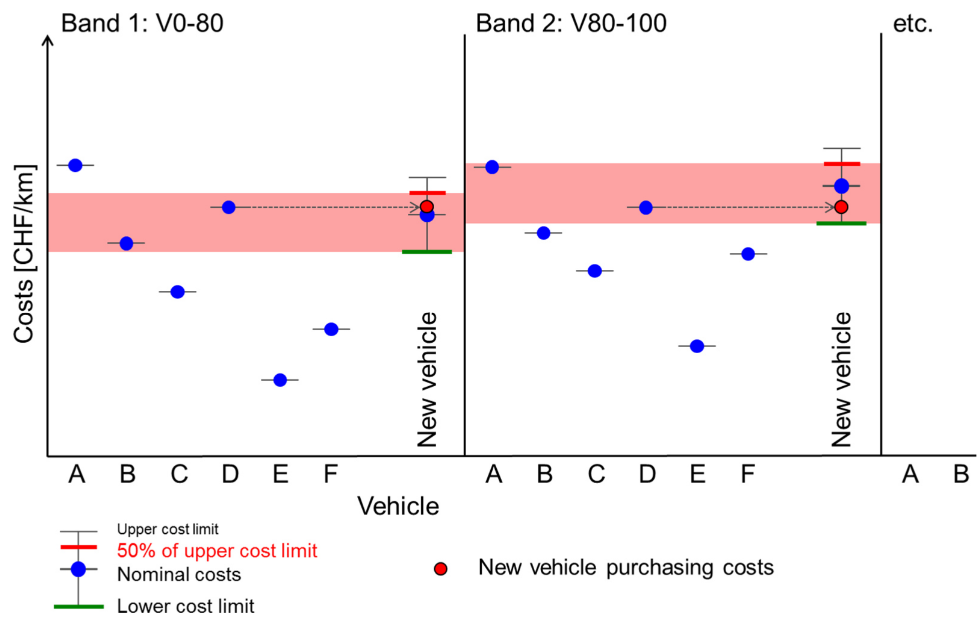


Figure 8-2: Rule for adopting vehicle reference costs for new vehicles

The background to the asymmetrical limits is as follows: If a new vehicle can adopt the vehicle reference costs of an existing vehicle with lower nominal costs, the infrastructure bears 100% of the delta between the two nominal costs. The vehicle is assigned a better price than it should have (see Figure 8-2: Band 2, new vehicle). In contrast, a vehicle can also be assigned a higher price than it should nominally have. In this case, the risk of the greatest deviations occurring and the delta are to be shared equally by the RU and IM.

8.1.5. Significant costs within a vehicle family

The base price wear incentivises vehicle concepts but not equipment features. Following this principle, vehicles with the same concept are grouped in one family with one vehicle type. This means that, for example, there is no differentiation between first and second class in the case of passenger cars. It is only possible to achieve finer differentiations through billing for freight wagons in category divisions of 4 t axle load, which is still a manageable system. In principle, however, the deviations within a vehicle family (e.g. with regard to the vehicle weights) may be so significant that it is no longer feasible to group them together.

If the total of all vehicle reference costs from the speed and radius bands of a single vehicle in the family deviates from the grouped costs of the vehicle family by more than 5%, management of a separate vehicle type is justified. The principle does not apply if structural measures are carried out on the running gear with a focus on strain reduction. If the effect on the costs is less than 5%, bilateral agreements are to be made with the vehicle pricing department.

8.2. Cost allocation for a new vehicle

In order to determine the lower and upper cost limit, the data uncertainty must be entered. This section is hidden in the Excel tool by means of grouping to ensure that the worksheet remains clear for the nominal cost calculation. The section can be opened at the side by clicking ⊞ or 2 (Figure 8-3).

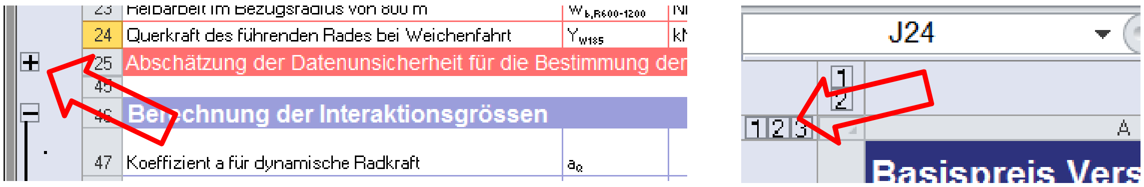


Figure 8-3: Opening hidden groupings in Excel

The section for information about data uncertainty (Figure 8-4) contains selection lists which are used to enter the relevant information.

Estimation of data uncertainty for the determination of the price limits					
Service weight deviation			- No series differences, new build: 1% - Old vehicles with refits: 2.5% - Old vehicles with refits, different RUs: 5%	2.5%	2.5%
Uncertainty regarding the unsprung mass due to drive/wheelset design			Exact mass data available: 0% No exact data available: - Trailing wheelset, block brakes: 0% - Trailing wheelset, disc brakes: 5% - Drive, fully sprung: 8% - Drive, partially sprung/unsprung: 15%	8%	5%
Longitudinal stiffness of the wheelset guidance			- cx ≥ 30 kN/mm: 40 kN/mm - 15 kN/mm ≤ cx < 30 kN/mm : 20 kN/mm - 8 kN/mm ≤ cx < 15 kN/mm : 10 kN/mm - cx < 8 kN/mm : 5 kN/mm	0% 5% 8% 15% 20 kN/mm	10 kN/mm
Uncertainty in the yaw damping			- No yaw damper: 0% - Characteristic known precisely: 0% - Characteristic estimated: 20%	20%	0%
Uncertainty regarding the mass moment of inertia of the running gear about the vertical axis			- Exact data from CAD: 20% - Data estimated: 40%	40%	40%
Frictional value of the frictional elements			- No frictional elements: 0.00 - μ < 0.08: 0.05 - 0.08 ≤ μ < 0.15 0.10 - μ ≥ 0.15 0.20	0.00	0.00

Figure 8-4: Entering data uncertainty in the Excel calculation table

The following selection options are available:

Influencing parameter	Description	Selection
Service weight deviation	- No series differences, new build	1.0%
	- Old vehicles with refits	2.5%
	- Old vehicles with refits, different RUs	5%
Uncertainty regarding the unsprung mass due to drive/wheelset design	- Exact mass data is available	0%
	- Trailing wheelset, block brakes	0%
	- Trailing wheelset, disc brakes	5%
	- Drive, fully sprung	8%
	- Drive, partially sprung/unsprung	15%
Longitudinal stiffness of the wheelset guidance	- $c_x \geq 30$ kN/mm	40 kN/mm
	- 15 kN/mm $\leq c_x <$ 30 kN/mm	20 kN/mm
	- 8 kN/mm $\leq c_x <$ 15 kN/mm	10 kN/mm
	- $c_x < 8$ kN/mm	5 kN/mm
Uncertainty in the yaw damping	- No yaw damper	0%
	- Characteristic known precisely	0%
	- Characteristic estimated	20%
Uncertainty regarding the mass moment of inertia of the running gear about the vertical axis	- Exact data from CAD	20%
	- Data estimated	40%
Frictional value of the frictional elements	- No frictional elements	0.00
	- $\mu < 0.08$	0.05
	- $0.08 \leq \mu < 0.15$	0.10
	- $\mu \geq 0.15$	0.20

Table 8-2: Selection options for entering the data uncertainty

The factors for modifying the input variables are determined automatically. The values from Table 8-1 are used for this purpose. The factors for W_b and Y_{W185} are determined by multiplying the sub-factors. The grouping must be opened in order to view this area.

		factor fu		factor fo	
Factor for Q0	$f_{u/o}Q_0$	0.9750	0.9750	1.0250	1.0250
Factor for mu	$f_{u/o}m_u$	0.9200	0.9500	1.0800	1.0500
Sub-factor for Wb from service weight deviation	$f_{u/o}W_b\Sigma m$	0.9809	0.9809	1.0191	1.0191
Sub-factor for Wb from wheelset guidance	$f_{u/o}W_bC_x$	0.9790	0.9320	1.0210	1.0680
Sub-factor for Wb from frictional elements	$f_{u/o}W_b\mu$	1.0000	1.0000	1.0000	1.0000
Factor for Wb	$f_{u/o}W_b$	0.9603	0.9142	1.0405	1.0884
Sub-factor for YW185 from service weight deviation	$f_{u/o}Y_{W185}\Sigma m$	0.9875	0.9875	1.0125	1.0125
Sub-factor for YW185 from wheelset guidance	$f_{u/o}Y_{W185}C_x$	1.0000	1.0000	1.0000	1.0000
Sub-factor for YW185 from yaw damping	$f_{u/o}Y_{W185}SD$	0.9740	1.0000	1.0260	1.0000
Sub-factor for YW185 from mass moment of inertia	$f_{u/o}Y_{W185}J_{zz}$	0.9834	0.9834	1.0166	1.0166
Sub-factor for YW185 from frictional elements	$f_{u/o}Y_{W185}\mu$	1.0000	1.0000	1.0000	1.0000
Factor for YW185	$f_{u/o}Y_{W185}$	0.9459	0.9711	1.0561	1.0293

Figure 8-5: Factors for the input variables for the calculation of the lower and upper cost limit

The input variables are multiplied by the factors. Figure 8-6 compares the nominal and modified values from the Excel table.

Running gear data			nominal		nominal * factor fu		nominal * factor fo	
Number of similar wheelsets per running gear type	$n_{RS/FW}$		2	2	2	2	2	2
Number of running gears for each running gear type per vehicle	n_{FW}		2	2	2	2	2	2
Number of similar driven wheelsets per vehicle	n_{TRS}		4	0	4	0	4	0
Number of similar wheelsets per vehicle	n_{RS}		4	4	4	4	4	4
Static vertical wheel force	Q_0	kN	75.00	50.00	73.13	48.75	76.88	51.25
Unsprung mass per wheel	m_u	kg	800.00	500.00	736.00	475.00	864.00	525.00
Wheel radius (nominal value for new wheels)	R_{Rad}	m	0.450	0.400	0.450	0.400	0.450	0.400
Maximum power at wheel	P_{Rad}	kW	150		150	0	150	0
Specific frictional energy in reference radius of 270 m	$W_{b,R<300}$	Nm/m	230.00	150.00	220.87	137.13	239.32	163.26
Specific frictional energy in reference radius of 343 m	$W_{b,R300-400}$	Nm/m	170.00	100.00	163.25	91.42	176.89	108.84
Specific frictional energy in reference radius of 480 m	$W_{b,R400-600}$	Nm/m	100.00	60.00	96.03	54.85	104.05	65.30
Specific frictional energy in reference radius of 800 m	$W_{b,R600-1200}$	Nm/m	50.00	25.00	48.02	22.85	52.03	27.21
Lateral force of leading wheel when travelling over points	Y_{W185}	kN	50.00	20.00	47.29	19.42	52.80	20.59

Figure 8-6: Nominal and modified values for the input variables

The upper and lower cost limits are calculated with these modified input variables using the same formulae as for the nominal cost calculation (see Section 6). Their values are shown next to the nominal values (Figure 8-7). The values for 50% of the upper limit are also calculated from the nominal costs and the upper cost limits.

		Summands						nominal	lower limit	upper limit	50% upper limit	definitive
$Crel_{Tpv}$	CHF/km			k.D3				0.0074883				0.0074883
$Crel_{V0-80}$	CHF/km	$k.D1_{V0-80}$	$k.D2_{V0-80}$	k.D3			k.D5	**0.0943495**	0.0903792	0.0983900	0.0963698	**0.0931379**
$Crel_{V80-100}$	CHF/km	$k.D1_{V80-100}$	$k.D2_{V80-100}$	k.D3			k.D5	**0.0994179**	0.0948773	0.1040592	0.1017386	**0.0979107**
$Crel_{V100-120}$	CHF/km	$k.D1_{V100-120}$	$k.D2_{V100-120}$	k.D3			k.D5	**0.1074675**	0.1019921	0.1130954	0.1102815	**0.1054641**
$Crel_{V120-140}$	CHF/km	$k.D1_{V120-140}$	$k.D2_{V120-140}$	k.D3			k.D5	**0.1171442**	0.1105127	0.1239948	0.1205695	**0.1145140**
$Crel_{V140-160}$	CHF/km	$k.D1_{V140-160}$	$k.D2_{V140-160}$	k.D3			k.D5					
$Crel_{V>160}$	CHF/km	$k.D1_{V<200}$	$k.D2_{V<200}$	k.D3			k.D5					
$Crel_{R<300}$	CHF/km	$k.D1_{R<300}$			$k.D4.1_{R<300}$	$k.D4.2_{R<300}$	k.D5	**0.5511231**	0.5243518	0.5790318	0.5650775	**0.5419830**
$Crel_{R300-400}$	CHF/km	$k.D1_{R300-400}$			$k.D4.1_{R300-400}$	$k.D4.2_{R300-400}$	k.D5	**0.1966341**	0.1846714	0.2093946	0.2030144	**0.1934358**
$Crel_{R400-600}$	CHF/km	$k.D1_{R400-600}$			$k.D4.1_{R400-600}$	$k.D4.2_{R400-600}$	k.D5	**0.1573680**	0.1470910	0.1679331	0.1626506	**0.1546429**
$Crel_{R600-1200}$	CHF/km	$k.D1_{R600-1200}$			$k.D4.1_{R600-1200}$		k.D5	**0.1257581**	0.1168522	0.1349822	0.1303702	**0.1228913**

Figure 8-7: Nominal vehicle reference costs, costs for the upper and lower limit, and definitive vehicle reference costs

Potential similarity to an existing vehicle is checked on the "Check" worksheet. This contains the vehicle reference costs for all existing vehicles in the billing system. The information about the new vehicle required for the check (vehicle category, speed category and number of wheelsets), as well as the calculated lower and 50% upper costs, is transferred automatically from the linked "Calculation" worksheet (rows 5 and 6).

The cells in the vehicle type list have conditional formatting. If the matches required for the price allocation are present, the cell is shown in blue. If all criteria are fulfilled, the vehicle designation is highlighted in the first column (Figure 8-8) and the check column is ticked.

Vehicle	Vehicle category	Train category	Number of wheelsets	V0-80	V80-100	V100-120	V120-140	V140-160	V>160	R<300	R300-400	R400-600	R600-1200	
				Vehicle reference costs										
RABe 5xx 4/8	**TZ**	**R**	**8**	**0.0963698**	**0.1017386**	**0.1102815**	**0.1205695**			**0.5650775**	**0.2030144**	**0.1626506**	**0.1303702**	50% upper limit
				0.0903792	**0.0948773**	**0.1019921**	**0.1105127**			**0.5243518**	**0.1846714**	**0.1470910**	**0.1168522**	lower limit
														Check
Vehicle 1	Lok	R	6	0.1510871	0.1635836	0.1837253	0.2082606			1.0107505	0.3967308	0.2893000	0.2270954	
Vehicle 2	Lok	R	4	0.1464876	0.1664992	0.1999846	0.2422003			1.2209357	0.4526667	0.3196579	0.2552310	
Vehicle 3	Lok	R	4	0.1206865	0.1297126	0.1441466	0.1615968	0.1823628	0.2507528	0.8254640	0.3066815	0.2064779	0.1597997	
Vehicle 4	PWg	R	4	0.0520682	0.0562905	0.0632168	0.0718009	0.0822351	0.1176784	0.4382514	0.1669084	0.1163389	0.0860851	
Vehicle 5	PWg	R	4	0.0474380	0.0505427	0.0555383	0.0616193			0.3424486	0.1385076	0.0992857	0.0705639	
Vehicle 6	PWg	R	4	0.0503859	0.0543582	0.0609105	0.0690738	0.0790404	0.1131098	0.3823754	0.1482373	0.1047794	0.0789117	
Vehicle 7	GWg	A	4	0.0581551	0.0616642	0.0671318				0.1960293	0.0864004	0.0748735	0.0659798	
Vehicle 8	GWg	A	4	0.0711102	0.0754558	0.0821320				0.2745221	0.1117063	0.0942799	0.0814529	
Vehicle 9	GWg	A	6	0.0361309	0.0383223	0.0419756				0.2306857	0.0619675	0.0484851	0.0395127	
Vehicle 10	GWg	A	8	0.1481907	0.1568820	0.1702344				0.8272118	0.3372819	0.2580901	0.1932251	
Vehicle 11	TZ	R	6	0.0662868	0.0694036	0.0742626	0.0800005			0.4152971	0.1658172	0.1200641	0.0851562	
Vehicle 12	TZ	R	8	0.0931379	0.0979107	0.1054641	0.1145140			0.5419830	0.1934358	0.1546429	0.1228913	✓
Vehicle 13	TZ	N	28	0.3360144	0.3557232	0.3872966	0.4255709	0.4712559	0.6225597	1.9256344	0.7106315	0.4939941	0.3940132	
Vehicle 14	TZ	R	16	0.2425713	0.2630215	0.2962891	0.3371856			1.8521284	0.7175811	0.5174221	0.3973726	
Vehicle 15	TZ	R	8	0.0801446	0.0836931	0.0893308	0.0961142			0.4522671	0.1914501	0.1422814	0.1032014	
Vehicle 16	TZ	R	10	0.0964468	0.1007025	0.1074541	0.1155673			0.5581133	0.2342828	0.1732180	0.1252778	
Vehicle 17	TZ	R	24	0.3103186	0.3327239	0.3690510	0.4135872	0.4672441		2.1253057	0.8530115	0.6058495	0.4575858	
Vehicle 18	TZ	R	8	0.0800067	0.0835925	0.0891918				0.5077586	0.2031229	0.1463229	0.0955132	
Vehicle 19	TZ	R	26	0.4324829	0.4653983	0.5184514	0.5831016	0.6605744	0.9184107	5.5763298	2.1930876	1.3455836	0.6757673	
Vehicle 20	TZ	R	4	0.0887816	0.0970709	0.1105639	0.1271543			0.8296564	0.3280981	0.2200207	0.1262102	
Vehicle 21	TZ	R	60	0.8966278	0.9762953	1.1067946	1.2682587	1.4642065	2.1280719	7.4470752	2.9457661	2.1194967	1.5323820	

Figure 8-8: Vehicle type list with highlighted matches for the cost allocation

In the example in Figure 8-8, all criteria are fulfilled for “Vehicle 12”. The vehicle reference costs for this vehicle now apply to the new vehicle. They are transferred to the "definitive" column on the "Calculation" worksheet (see Figure 8-7).

Multiplying the definitive vehicle reference costs by the scaling factor produces the definitive vehicle prices (Figure 8-9). These prices are used for the billing in the train-path pricing system.

S			2.35	2.35
			nominal	**definitive**
C_{Tpv}	CHF/km	$Crel_{Tpv}$ * S	0.0175975	0.0175975
$\mathbf{C_{V0-80}}$	CHF/km	$Crel_{V0-80}$ * S	**0.2217213**	**0.2188741**
$\mathbf{C_{V80-100}}$	CHF/km	$Crel_{V80-100}$ * S	**0.2336321**	**0.2300901**
$\mathbf{C_{V100-120}}$	CHF/km	$Crel_{V100-120}$ * S	**0.2525486**	**0.2478406**
$\mathbf{C_{V120-140}}$	CHF/km	$Crel_{V120-140}$ * S	**0.2752889**	**0.2691079**
$\mathbf{C_{V140-160}}$	CHF/km	$Crel_{V140-160}$ * S		
$\mathbf{C_{V>160}}$	CHF/km	$Crel_{V160-200}$ * S		
$\mathbf{C_{R<300}}$	CHF/km	$Crel_{R1-300}$ * S	**1.2951393**	**1.2736601**
$\mathbf{C_{R300-400}}$	CHF/km	$Crel_{R300-400}$ * S	**0.4620901**	**0.4545741**
$\mathbf{C_{R400-600}}$	CHF/km	$Crel_{R400-600}$ * S	**0.3698148**	**0.3634108**
$\mathbf{C_{R600-1200}}$	CHF/km	$Crel_{R600-1200}$ * S	**0.2955315**	**0.2887946**

Figure 8-9: Calculating the definitive vehicle prices

This completes the price calculation.

9. Abbreviations/Formula symbols

Abbreviation	Meaning
aq	Uncompensated lateral acceleration
A_{Rad}	Wheel contact patch (contact area; on straight sections)
$A_{Rad,eff}$	Wheel contact area used to calculate T_{pv}
C_{rel}	Vehicle reference costs
C	Vehicle price
c_x	Longitudinal stiffness of the wheelset guidance
D_j	Damage
RU	Railway undertaking
IM	Infrastructure manager
k_j	Cost calibration factor
MBS	Multi-body system
m_u	Unsprung mass
n_{FW}	Number of leading wheelsets = number of running gears
n_{RS}	Number of wheelsets which contribute to damage
n_{TRS}	Number of driven wheelsets which contribute to damage
P_{Rad}	Transferred power at wheel contact point
Q	Dynamic vertical wheel force
Q_0	Static vertical wheel force
R	Curve radius
R_{Rad}	Wheel radius
R_{Sch}	Rail radius
S	Scaling factor
TPS	Train-path pricing system
T_{pv}	Traction power value (power density in effective wheel contact patch)
T_x	Longitudinal slip force
T_y	Transverse slip force
ü	Cant
üf	Cant deficiency
V	Vehicle speed
V_{zul}	Maximum permissible vehicle speed
V_{Wzul}	Permissible speed on 40 km/h points
W_b	Frictional energy (energy dissipation on leading wheelset on curve) Product of frictional force and slips)
X	General parameter
Y_{W185}	Dynamic guiding force on an EW185 set of points
μ	Frictional value of the frictional elements used in the multi-body model
v_x	Longitudinal slip
v_y	Transversal slip
2a*	Bogie distance
$2a^+$	Wheelset distance
Index	
i	Vehicle
j	Damage effect
k	Running gear type

10. References

[1] Verordnung des BAV über den Eisenbahn-Netzzugang (Track Access Ordinance of the Swiss Federal Office of Transport; NZV-BAV) , 21.09.2016, Annex 1a

[2] EN 14363:2016: "Railway applications - Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behaviour and stationary tests; English version, CEN European Committee for Standardization, March 2016

[3] GM/TT0088, Permissible Track Forces for Railway Vehicles,
Revision: A, Date: OCT 1993

[4] Dubbel – Taschenbuch für den Maschinenbau, Ausgabe 21 (Handbook of Mechanical Engineering, Edition 21), ISBN: 3540221425
Springer Verlag, 2004

[5] ERRI B176 „Bogies with steered or steering wheelsets“
European Rail Research Institute (ERRI), 1989

[6] Abschlussbericht Verschleissfaktor-Fahrbahn, SBB Infrastruktur - Anlagenmanagement Fahrbahn, 2016

[7] I. Nerlich „ Wie wirtschaftlich ist gleisschonendes Rollmaterial… wie einen Verkehr von morgen in der zukünftigen Auswirkung auf Gleisinstandhaltungen beziffern?“
ZEV Rail Tagungsband SFT Graz 2014, S138 ff

[8] www.onestopshop.ch / Services and prices / Train-path billing

[9] www.onestopshop.ch / Services and prices / Vehicle pricing

[10] www.onestopshop.ch / Technischer Netzzugang (Technical network access) / Rollmaterialdaten (Rolling stock data)

11. Contacts

11.1. Train-path price billing

Main contact for RUs and owners for any issues relating to train-path price billing:
SBB Infrastructure, Train-path sales department
onestopshop@sbb.ch

11.2. Vehicle pricing department

Contact for RUs, owners, manufacturers, etc. for any issues relating to vehicle price calculation:
SBB Infrastructure, Track department
oss.vehiclepricing@sbb.ch

11.3. BAV

Swiss Federal Office of Transport, Finance department:
marktzugang@bav.admin.ch
Tel.: +41 58 462 05 50

12. Annex: Sample parameter data set

The section below gives a theoretical example of a model parameter data set for a fictional vehicle (4-axle locomotive). It shows the basic data required to create a simple model.

The form of the parameter data set selected in the example is not binding. For detailed models, the volume of data may be considerably larger.

12.1. Mass data

The mass data provides the necessary information about the bodies appearing in the MBS model. As well as the mass itself, the centre of mass and mass moments of inertia are also provided. It is important to specify the respective reference system for the coordinates.

		Mass	Centre of mass coordinates				Mass moments of inertia about the centre of mass		
		m [kg]	x [m]	y [m]	z [m]		Jxx [kgm²]	Jyy [kgm²]	Jzz [kgm²]
Unsprung mass									
Wheelset including brake discs, bull gear	1, 3	2600.0	1.420	-0.072	-0.623	1)	1'300.00	300.00	1'300.00
	2, 4	2600.0	-1.420	0.072	-0.623	1)	1'300.00	300.00	1'300.00
Wheelset bearings including 50% primary suspension, etc.	1, 3	220.0	1.450	+/-1.000	-0.500	1)	2.00	5.00	5.00
	2, 4	220.0	-1.450	+/-1.000	-0.500	1)	2.00	5.00	5.00
Partially sprung mass									
Motor and gears	1, 3	3385.0	0.968	0.0846	-0.625	1)	1'330.00	330.00	1'330.00
	2, 4	3385.0	-0.968	-0.0846	-0.625	1)	1'330.00	330.00	1'330.00
Mass with primary suspension									
Running gear frame including 50% suspension, brakes, etc.	1	4000.0	5.000	0	-0.500	2)	3'000.00	4'700.00	7'600.00
	2	4000.0	-5.000	0	-0.500	2)	3'000.00	4'700.00	7'600.00
Mass with secondary suspension									
Body with proportional bogie masses		50000.0	0.000	0	-1.820	2)	80'000.00	850'000.00	800'000.00
Reference systems for the coordinates:									
1) Top of rail, centre of running gear									
2) Top of rail, centre of body									

Table 12-1: Mass data

12.2. Geometric data

The geometric data contains information about the position of the contact points for the coupling elements used to connect the bodies. Information about the respective reference system is required in this case as well.

Coupling point	Coordinates					
	x [m]	y [m]	z [m]	x [m]	y [m]	z [m]
Wheelset	1, 3			2, 4		
Reference point (rel. top of rail, centre of running gear)	1.400	0.000	-0.500	-1.400	0.000	-0.500
Wheelset bearing, right	0.000	1.000	0.000	0.000	1.000	0.000
Wheelset bearing, left	0.000	-1.000	0.000	0.000	-1.000	0.000
Bull gear bearing	0.000	-0.530	0.000	0.000	0.530	0.000
Nose-suspended motor bearing	0.000	0.550	0.000	0.000	-0.550	0.000
Wheelset bearing housing	1, 3			2, 4		
Reference point (rel. top of rail, centre of running gear)	1.400	1.000	-0.500	-1.400	1.000	-0.500
Wheelset guidance, right	0.000	0.000	0.000	0.000	0.000	0.000
Wheelset guidance, left	0.000	0.000	0.000	0.000	0.000	0.000
Primary damper, right	0.000	0.200	-0.170	0.000	0.200	-0.170
Primary damper, left	0.000	-0.200	-0.170	0.000	-0.200	-0.170
Motor, gears	1, 3			2, 4		
Reference point (rel. top of rail, centre of running gear)	0.900	0.000	-0.500	-0.900	0.000	-0.500
Torque support	-0.500	-0.200	0.400	0.500	0.200	0.400
Bull gear bearing	0.500	-0.530	0.000	-0.500	0.530	0.000
Nose-suspended motor bearing	0.500	0.550	0.000	-0.500	-0.550	0.000
Running gear	1			2		
Reference point (rel. top of rail, centre of body)	5.000	0.000	0.000	-5.000	0.000	0.000
Wheelset guidance 1r	1.500	1.000	-0.500	1.500	1.000	-0.500
Wheelset guidance 1l	1.500	-1.000	-0.500	1.500	-1.000	-0.500
Wheelset guidance 2r	-1.500	1.000	-0.500	-1.500	1.000	-0.500
Wheelset guidance 2l	-1.500	-1.000	-0.500	-1.500	-1.000	-0.500
Primary damper 1, right	1.500	1.200	-1.150	1.500	1.200	-1.150
Primary damper 1, left	1.500	-1.200	-1.150	1.500	-1.200	-1.150
Primary damper 2, right	-1.500	1.200	-1.150	-1.500	1.200	-1.150
Primary damper 2, left	-1.500	-1.200	-1.150	-1.500	-1.200	-1.150
Secondary spring, right, outside	0.000	1.180	-0.900	0.000	1.180	-0.900
Secondary spring, right, inside	0.000	0.900	-0.900	0.000	0.900	-0.900
Secondary spring, left, outside	0.000	-1.180	-0.900	0.000	-1.180	-0.900
Secondary spring, left, inside	0.000	-0.900	-0.900	0.000	-0.900	-0.900
Vertical damper, right	0.300	1.300	-0.450	0.300	1.300	-0.450
Vertical damper, left	-0.300	-1.300	-0.450	-0.300	-1.300	-0.450
Lateral damper	0.000	0.600	-0.400	0.000	0.600	-0.400
Traction rod, bogie pin	0.000	0.000	-0.600	0.000	0.000	-0.600
Yaw damper, right	-0.200	1.300	-0.700	-0.200	1.300	-0.700
Yaw damper, left	0.200	-1.300	-0.700	0.200	-1.300	-0.700
Torque support 1	0.400	-0.200	-0.900	0.400	-0.200	-0.900
Torque support 2	-0.400	0.200	-0.900	-0.400	0.200	-0.900
Lateral bump-stop	0.000	0.000	-0.900	0.000	0.000	-0.900
Carbody						
Reference point (rel. top of rail, centre of body)	0.000	0.000	0.000			
Secondary spring 1, right, outside	5.000	1.200	-1.500			
Secondary spring 1, right, inside	5.000	0.900	-1.500			
Secondary spring 1, left, outside	5.000	-1.200	-1.500			

Coupling point	Coordinates					
Secondary spring 1, left, inside	5.000	-0.900	-1.500			
Secondary spring 2, right, outside	-5.000	1.200	-1.500			
Secondary spring 2, right, inside	-5.000	0.900	-1.500			
Secondary spring 2, left, outside	-5.000	-1.200	-1.500			
Secondary spring 2, left, inside	-5.000	-0.900	-1.500			
Secondary vertical damper 1, right	5.200	1.400	-1.000			
Secondary vertical damper 1, left	4.600	-1.400	-1.000			
Secondary vertical damper 2, right	-4.600	1.400	-1.000			
Secondary vertical damper 2, left	-5.250	-1.400	-1.000			
Yaw damper 1, right	3.800	1.450	-0.800			
Yaw damper 1, left	6.100	-1.450	-0.800			
Yaw damper 2, right	-6.100	1.450	-0.800			
Yaw damper 2, left	-3.800	-1.450	-0.800			
Lateral damper 1	5.000	0.200	-0.300			
Lateral damper 2	-5.000	-0.200	-0.300			
Bogie pin 1	5.000	0.000	-0.500			
Bogie pin 2	-5.000	0.000	-0.500			
Lateral bump-stop	5.000	0.000	-0.900			

Table 12-2: Coupling coordinates for the force elements

12.3. Characteristics of the coupling elements

Most of the parameters for the coupling elements provide information about stiffness and damping. Depending on the modelling, the information is provided as individual values for the respective components or as overall values which group together the effective stiffness or damping for multiple components (system stiffness, parasitic stiffness). The parameters for frictional elements may provide additional information

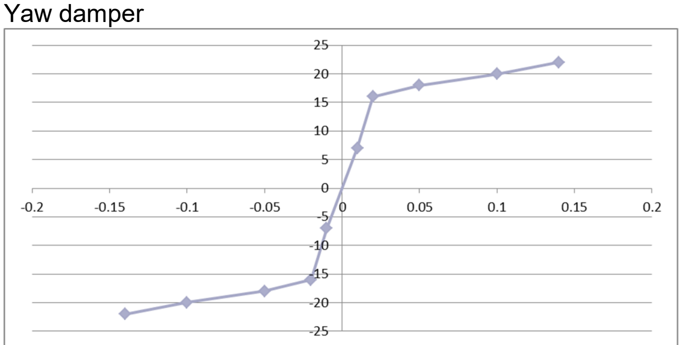
Coupling element	Unit	Direction		
		x	y	z
Primary level (values for each wheelset side)				
Stiffness	kN/mm	20.0	15.0	20.0
Primary damper				
Damping of vertical damper	kNs/m			45.0
Effective overall stiffness	kN/mm			22.0
Secondary level (values for each bogie side)				
Stiffness	kN/mm	0.025	0.4	1.4
Lateral damper				
Damping of lateral damper	kNs/m		60	
Effective overall stiffness	kN/mm		10	
Secondary vertical damper				
Damping of vertical damper	kNs/m			70
Effective overall stiffness	kN/mm			15
Yaw damper				
Nominal damping value	kNs/m	900		
Effective overall stiffness	kN/mm	10		
Torque support				
Stiffness (linear) [kN/mm]	kN/mm			175

Table 12-3: Parameter data for coupling elements

12.4. Characteristics for coupling elements

If components demonstrate non-linear behaviour, their properties are described with a characteristic.

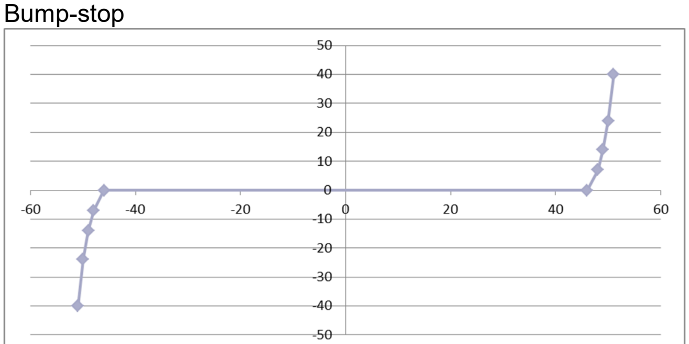
Yaw damper



Speed	m/s	-0.14	-0.1	-0.05	-0.02	-0.01	0.01	0.02	0.05	0.1	0.14
Force	kN	-22	-20	-18	-16	-7	7	16	18	20	22

Figure 12-1: Example of a non-linear damper characteristic

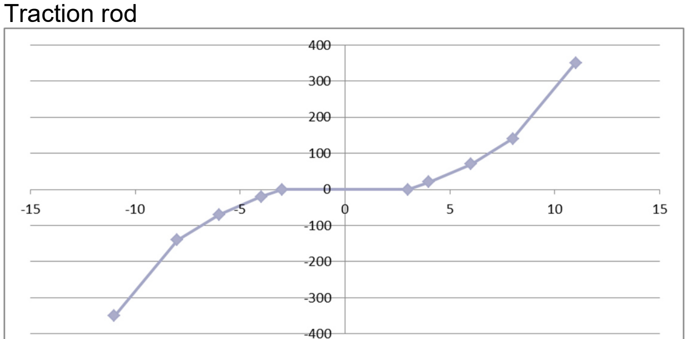
Bump-stop



Distance	mm	-51	-50	-49	-48	-46	46	48	49	50	51
Force	kN	-40	-24	-14	-7	0	0	7	14	24	40

Figure 12-2: Example of a non-linear stop characteristic

Traction rod



Distance	mm	-11	-8	-6	-4	-3	3	4	6	8	11
Force	kN	-350	-140	-70	-20	0	0	20	70	140	350

Figure 12-3: Example of a non-linear stiffness characteristic

13. Annex: Approval as independent inspection body by BAV

13.1. Basic requirements

The BAV can approve independent inspection bodies for the calculation of the vehicle prices in accordance with Art. 1 para. 4 of the Track Access Ordinance of the Swiss Federal Office of Transport (NZV-BAV; SR 742.122.4) provided that the bodies meet the requirements regarding technical expertise and independence; see below.

a. Technical expertise:
The person responsible for the inspection of the calculation has the following minimum qualifications:

- University degree in engineering or a mathematical/scientific subject
- More than 5 years' experience in the field of running gear engineering and vehicle homologation
- Evidence of extensive (more than 5 years') experience in modelling and calculating multi-body systems

b. Independence:
The person responsible for the inspection of the calculation

- Must not perform any tasks in connection with the subject of the inspection (vehicle) other than the inspection tasks specified in these instructions.
- Must not have any personal interest in the result of the inspection or have had any prior involvement with the subject of the inspection in any other role or be biased in any other way.
- Must be independent from the persons with an interest in the result.

The customer must respect this independence and, in particular, must not put any pressure on the person responsible for the inspection of the calculation with regard to the expected result.

13.2. Application and inspection

Applications for approval must be submitted to the BAV Finance department (see 11.3. Contacts) and must include a completed self-declaration using the sample form below as a minimum requirement.

The BAV will examine the plausibility of the application and assess the suitability of the body by obtaining additional information from the applicant, the references provided and from other appropriate sources as necessary. If the applicant is judged to be suitable, the BAV will issue its approval in writing.

The FOT publishes a list of recognised assessement bodies on its website[4] (in german only).

[4] https://www.bav.admin.ch/bav/de/home/verkehrsmittel/eisenbahn/fachinformationen/trassenpreis.html

13.3. Sample form

Company name

	Details (to be completed by the applicant)
Company name	
Postal address	Street Post code Town/city Country
Telephone	
Fax	
E-mail	
URL /	

Responsible contact

	Details (to be completed by the applicant)
First and last name	
Role / at company since	
Department and role	
Relevant training/education	
Relevant experience	
Telephone	
Fax	
URL / e-mail	
References	

Self-declaration

I/We can confirm the following:

a. Technical expertise:
The person responsible for inspection of the calculating the vehicle prices is competent and has the following minimum qualifications:

- University degree in engineering or a mathematical/scientific subject
- More than 5 years' experience in the field of running gear engineering and vehicle homologation
- Evidence of extensive (more than 5 years') experience in modelling and calculating multi-body systems

b. Independence:
The company shall ensure that the inspection tasks are performed independently.

c. Diligence:
The company shall ensure that the assigned inspection tasks are performed with the utmost diligence and conscientiousness. Any discrepancies with regard to the customer or the data supplier shall be reported to the BAV.

Date and signature:

....