RIVAS
Railway Induced Vibration Abatement Solutions
Collaborative project

Relevant parameters for a reference test track
Deliverable D1.7

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1. EXECUTIVE SUMMARY

The present report identifies the parameters required for characterising the vibration performance of the track. These parameters will be used in the further work of task 1.4 of the RIVAS project, where a reference track will be defined. This reference track is intended for modelling and measurement purposes. The reference track will provide the ingredients for a standard track model, against which the vehicle parameters can be tuned such that the performance of the total vehicle track system is optimised. The reference track will also provide ingredients for a possible real reference track. This reference track is intended to be used for measurement purposes. The measurements made on the reference track will serve to check the vibrational performance of an actual vehicle against target or limit values. Such limit values may be part of a homologation process, if this will include vibration performance in a future phase, or part of a performance test during commissioning of a new vehicle.

The current report presents parameters for track, soil and vehicle. For each parameter, a range is given where practical values of that particular parameter can be chosen. The range is limited by the operational and safety constraints of the railway system. In addition, for each parameter the value that is most commonly found in European heavy rail systems is indicated. As an outlook to the further work in task 1.4, for each parameter the performance of the subsystem is related to one of the extreme values of the range of that parameter. In the current stage of the work, this relationship is only an educated guess. In future work, the relationship will have to be precised and quantified.

2. TABLE OF CONTENTS

3. CHAPTERS

3.1 INTRODUCTION

Railway induced ground borne vibrations result from the interaction between a moving rail vehicle, the track superstructure and the subsoil. This system of vehicle, track and soil represents the source of ground borne vibrations. This source interacts with the surrounding soil; the vibrational energy propagates in different wave forms. The propagating waves may interact with building structures and excite these structures to vibrations, which are dominated by the modal behaviour of the building structure. The vibrating structure may give rise to vibrations being noticed by persons in the building and possibly to a response in the form of annoyance, fear, sleep disturbance, etc. These responses, when strong enough and when occuring regularly over a long period of time, may cause health problems.

The interaction is complex and depends on many different parameters. If one wants to control the vibration level at the source - which traditionally is the most efficient way to control - , one might want to interfere with these parameters.

Obviously, the degree of freedom to interfere is limited. For every single parameter, there is a distinct range of realistic values, within which the optimized value can be chosen. There are many constraints that limit this range, such as material properties, but also constraints introduced by economics, safety, operational and practical considerations.

Another inherent constraint is that many of the parameters are correlated and not entirely independent. Changing the value of one parameter often implies a requirement to change other parameters at the same time for the system to work properly.

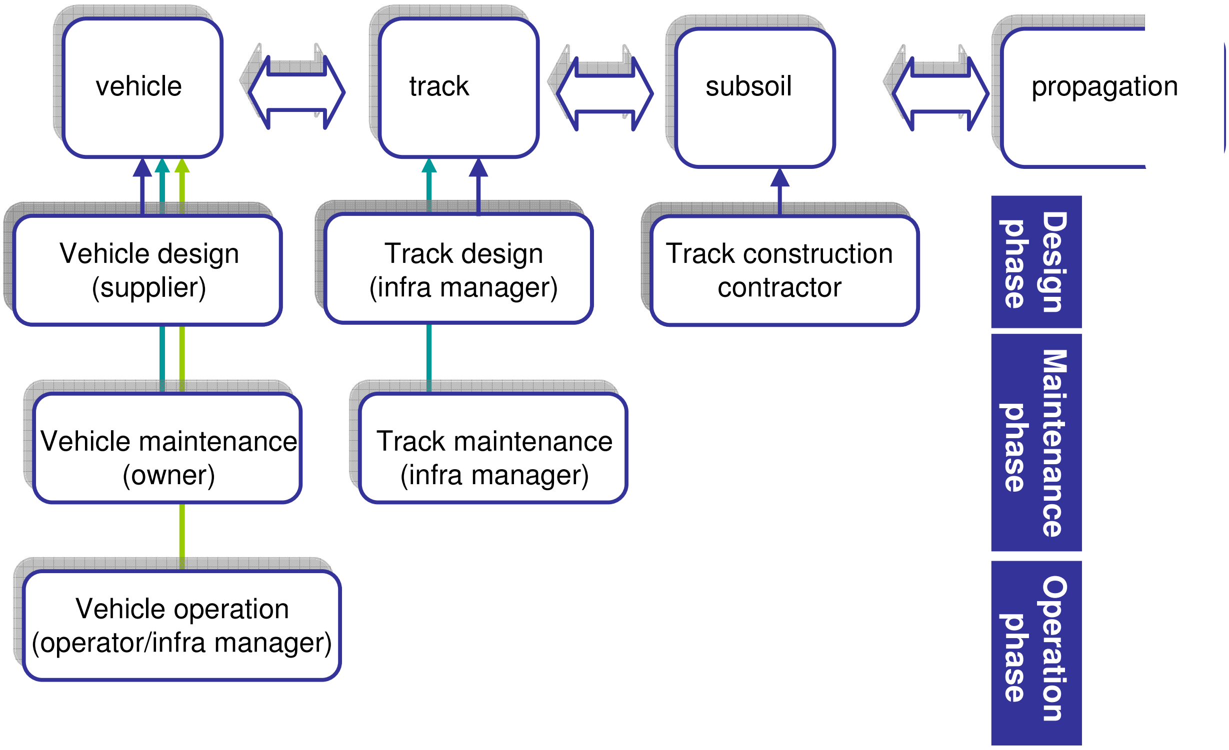
This interdependence of parameters in the total system causes an obstacle to virtually any interference into the railway system. This is particularly noticeable since the restructuring of the former railway undertakings. Today, there is a range of different parties, responsible for the design, construction and maintenance of the track (the infrastructure manager), for the design and maintenance of the vehicle (the vehicle owner and the vehicle supplier), for the operation of the vehicle (the railway operator) and sometimes even for the maintenance of the subsoil condition (the track maintenance contractor).

In an ideal situation, the different parties would work together in optimizing the whole system such that the vibrational output of the source system would be minimized. In an existing situation, where a particular track and vehicle configuration are given, it would require the interaction of all responsible parties to change that system into an optimized system with reduced vibrational output. Usually, the result is sub-optimal because only one element of the system, usually the track, is changed.

Ideally, the chances are more efficient in a design situation, where the degrees of freedom are maximal. For example: if the track designer would know the relevant parameters of the rolling stock that will be operated on the track to be designed, and in addition he would know the subsoil characteristics, these vehicle and subsoil parameters could be used as boundary conditions for the track design. Vice versa, if the vehicle designer would know the exact track and subsoil characteristics he could design the vehicle such that, in combination with that particular track and subsoil, it would result in a system that generates low vibrational energy.

The situation is illustrated in graph 1. Here we distinguish three phases:

- Design phase: maximum degree of freedom to optimize track and vehicle, but there are clearly interdependencies between track and vehicle design, which are usually not fully exploited
- Maintenance phase: limited degree of freedom, unless both track and vehicle are modified
- Operational phase: Very limited degree of freedom



Graph 1. Phases in the life cycle of track and vehicle, and responsibilities for modifications and optimisations

In addition to these constraints, as we can see in the Graph, the number of parties involved in improving the system becomes less when we go from the design process to the operational phase. In the end, only the vehicle operator has some options to improve his contribution to the overall system.

In designing the reference track, we focus on each of these three phases.

3.2 OBJECTIVES

The current report sets out the objectives and approach of task 1.4, within Work package 1 of the RIVAS project. Work package 1 deals with assessment and monitoring procedures.

The main objective of WP1 is to establish test procedures for the performance of vibration mitigation measures under realistic conditions.

Within Work package 1, task 1.4 focuses on the interface between the vehicle and the track.

The objective of task 1.4 is to produce a novel approach to separate the responsibilities for optimised vibration performance between the vehicle manufacturer/supplier and railway undertaker/operator on the one side and infrastructure manager on the other.

The approach of WP 1.4 is to define a standard set of values for track and subsoil related parameters, thus allowing the vehicle designer to optimize the vehicle parameters in a way that allows optimizing the performance of the overall system. The standard values shall fulfil several requirements, viz.

- They shall be *realistic*, i.e. they should not affect non-vibrational constraints that would lead to the track and subsoil being out of line with general infrastructure requirements.
- The standard values shall be *representative* for the state of the art of modern track design, or it shall at least be possible to convert the resulting vibration performance, assessed with the standard set of parameters values, into a corresponding vibration performance on such a state of the art track.

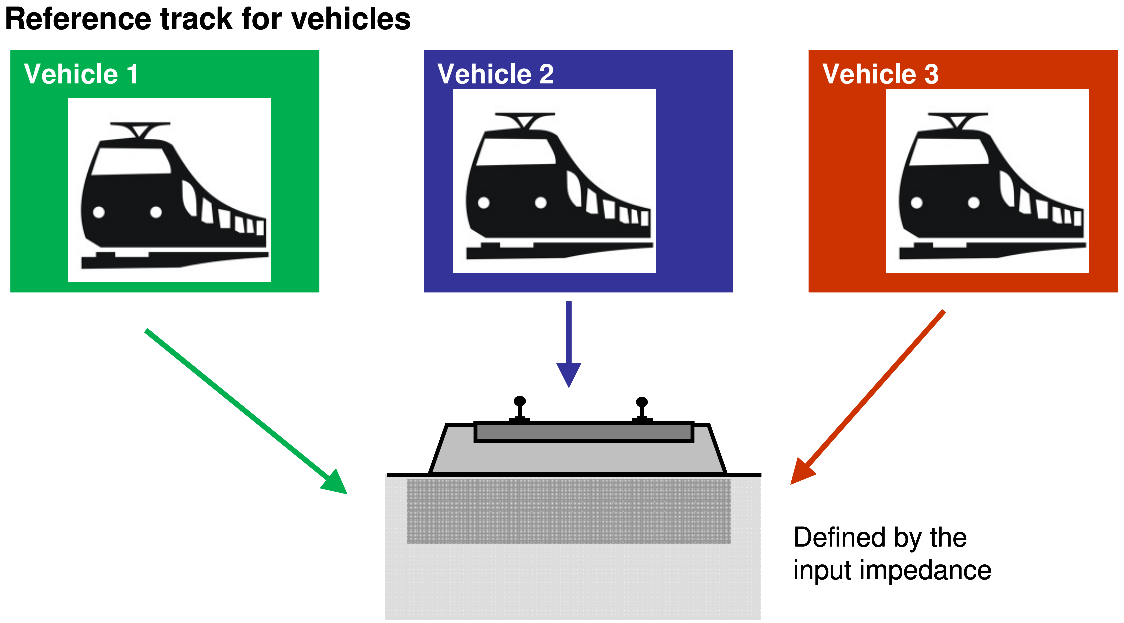
Once these parameter values have been defined, turning them into a real track superstructure would allow testing the vibration performance of a vehicle without the track performance interfering with the result.

- Therefore, the set of track parameter values need to be *consistent* and
- it needs to be *feasible* to actually construct the track such that these values are present.

If such a track can be constructed, then it would serve two purposes:

- First, it would be the reference track against which the vehicle designer would design the vehicle in a harmonized and consistent way, such that it would create vibration levels as low as feasible. Once the vehicle parameters are known, the actual behaviour on any practical track could be predicted by modifying only the track properties in the prediction model. For this purpose, the track does not need to actually exist. It is sufficient if the track parameters have been standardised, so that the vehicle designer can use it in his design process.
- Second, it would serve as a test track, where actual vehicles could be tested for compliance with a given procurement specification. For this purpose, we may think of an actually existing track section, to be used for field measurements, but with “virtual testing” and “virtual homologation” gaining more interest and real application, even this test track may only be a set of parameters, to be used in the virtual testing environment.

Track for vehicle homologation



As a first step, in the next paragraph a complete list of track, vehicle and subsoil related parameters is presented, together with the typical values found in state of the art railway systems.

3.3 RELEVANT PARAMETERS

3.3.1 Track parameters

For a comprehensive overview of track parameters, reference is made to deliverables D3.2 and D5.1 respectively [3],[2]. The following table 1 is based on table 3 of [3]. The table intends to present maximum and minimum values for each of the parameters, including a “nominal” or “standard” value representative for most of the European tracks.

Table 1. Track parameters(ballasted track)

Ballasted track					
	Parameter	Unit	Extreme 1	Extreme 2	Standard case value
	Sleeper distance (“span”)	m	0.7	0.2 (theoretically achievable)	0.6
	Sleeper length	m	2.4	2.6	2.5
	Sleeper mass	kg	Wood: appr. 80	Concrete monoblock: appr. 350 kg	285
	Sleeper Modulus of Elasticity	N/m^2	8 x 10^9	30 x 10^9	30 x 10^9
	Sleeper Poisson’s ratio		0.1	0.2	0.15
	Rail fastener vertical dynamic stiffness	N/m	60 x 10^6	4000 x 10^6	3000 x 10^6
	Rail fastener lateral dynamic stiffness	N/m	20 x 10^6	400 x 10^6	20 x 10^6
	Rail fastener loss factor		0.05	0.3	0.2
	Under sleeper pad vertical dynamic stiffness	N/m	50 x 10^6	600 x 10^6	400 x 10^6
	Rail type		UIC 54	UIC 60	UIC 60
	Rail mass per unit length	kg/m	54 kg/m	60 kg/m	
	Rail bending stiffness	N/m^2	5 x 10^6	13 x 10^6	6.4 x 10^6

Ballasted track (cont'd)

	Parameter	Unit	Extreme 1	Extreme 2	Standard case value
	Ballast height	m	0.25	0.40	0.30
	Ballast mass	kg/m^1	2300	3700	2750
	Ballast stiffness	N/m^2	300 x 10^6	600 x 10^6	330 x 10^6
	Ballast shear wave velocity	m/s			300
	Shear damping ratio				2%
	Ballast dilatational wave velocity	m/s			600
	Dilatational damping ratio				2%
	Under ballast mat stiffness	N/m^3	15 x 10^6	100 x 10^6	50 x 10^6

The above table 1 includes the relevant track parameters that can be "tuned" such that the track can be considered a reference track, either for modelling purposes or for measurement purposes. The optimised value for both of these purposes will be the subject of further work in Work package 1, task 4.

In the above table, a range of parameters has not been included, either because they are considered not relevant for vibration excitation or generation, or because it is not practically feasible to tune them. This includes the following parameters:

- Track roughness (dB re 10^{-6} m rms as a function of wavelength in m)
- Presence of rail joints (m^{-1})
- Presence of switches (m^{-1})
- Presence of curves and if any, radius of the curve (m)
- Track decay rate (dB/m) is assumed to be described by the rail pad stiffness
- Rail cant (is assumed to be irrelevant)
- Rail twist (is assumed to be irrelevant)
- Vertical rail evenness

In table 1, the track parameters are specified for ballasted track only. In the current stage of the work in task 1.4, non-ballasted track must be considered as a candidate track for the reference, both for modelling and measurement. Therefore, the following table 2 presents the parameters for a non-ballasted (i.e. slab) track. For these parameters, reference is made to D3.3 [5].

Table 2. Track parameters(non-ballasted track)

Non-ballasted track				
Parameter	Unit	Extreme 1	Extreme 2	Standard case value
Slab thickness	m	0.3 m	0.6 m	0.5
Slab mass (double track)	kg/m^1	8600	17000	14400
Fastener vertical dynamic stiffness	N/m	15 x 10^6	120 x 10^6	40 x 10^6
Fastener lateral dynamic stiffness	N/m	7 x 10^6	15 x 10^6	10 x 10^6

In the above table 2, only the parameters have been identified which are additional to the parameters in table 1, in the case of a non-ballasted track. It is assumed, that the other parameters and their range remain the same. This may not be entirely true. Some of the rail bending stiffness could be provided by the stiffness of the slab. In further work within WP 1.4, this issue will be addressed.

3.3.2 Subsoil Parameters

Similar to the track parameters, soil and subsoil parameters are derived from [3]. A summary of the relevant parameters is presented in table 3.

Table 3. ***Subsoil/ground parameters***

Soil parameters					
	Parameter	Unit	Extreme 1	Extreme 2	Value in standard case
	Dilatational wave velocity	m/s	1700 (soft clay)	2000 (chalk)	1800
	Dilatational damping ratio				2%
	Shear wave velocity	m/s	120 (soft clay)	1100 (chalk)	200
	Shear damping ratio				2%
	Density	kg/m^3	2000	2500	2000
	Upper Layer depth	m	1.5	5.0	3.0

When defining a reference soil for a reference track in order to design and model a low vibration vehicle, one can modify the soil characteristics and parameters as desired. However, in practice, changing the soil characteristics will be difficult and certainly expensive. In the further work, the soil parameters will be treated as “lower limits”, in other words: when identifying a suitable site for vehicle measurement, the soil should at least comply with certain limit values, in order for the measured result to be consistent, reproducible and representative. In future work, these limit values will be investigated and defined.

3.3.3 Vehicle parameters

Vehicle parameters are not the key issue in the current report. After all, the intention of task 1.4 is to define track characteristics such that the track is suitable for modelling and measuring the vibrational performance of a vehicle. Nevertheless, when defining the characteristics of this reference track, we have to take into account that the vehicle parameters might vary significantly. In principle, the reference track should be capable to cope with this wide range of different vehicles and different vehicle characteristics. This applies for example to the following, quite different vehicle types:

- Heavy rail passenger vehicles, including multiple units, with conventional speed,
- Heavy rail passenger vehicles, including multiple units, designed for high speed (200 kph and more),
- Heavy rail freight vehicles,
- Light rail passenger vehicles.

Although the emphasis in the RIVAS project is on the heavy rail conventional speed, the two other vehicle classes will be included in the assessment for a reference test track. The range of certain vehicle parameters depends on the vehicle class under concern.

Table 4. Vehicle parameters [2]

Vehicle parameters					
	Parameter	Unit	Extreme 1	Extreme 2	Value in standard case
	Vehicle speed	km/h	40	300	100
	Vehicle body mass (EMU)	kg	30,000	45,000	32,000
	Vehicle body mass (locomotive)	kg	7.500	10,000	9,000
	Vehicle body mass (freight wagon)	kg	2.000	3,000	2,000
	Wheelset unsprung mass	kg	1,200	2,800	1,800
	Bogie mass	kg	4,000	6,000	5,000
	Primary suspension vertical dynamic stiffness	N/m	1.8 x 10^6	8.0 x 10^6	2.6 x 10^6
	Primary suspension	Ns/m	20 x 10^3	40 x 10^3	

	vertical damping				
	Secondary suspension vertical dynamic stiffness	N/m	0.4 x 10^6	1.0 x 10^6	0.8 x 10^6
	Secondary suspension damping	Ns/m	10 x 10^6	60 x 10^6	30 x 10^6
	Wheel distance within the bogie	m	1.8 (freight car)	2.9	2.5
	Bogie distance	m	12.0	28.0	14.0
	Axle load	tonnes	8	22.5	22.5
	Wheel out of roundness wavelength	m	2.9 (disk braked wheels)	0.03 (block braked wheels)	0.03

In [5], it was proposed to use the arithmetic average between upper and lower value as the reference value for the vehicle model. Where a cell in the right hand column is left blank in table 4, this arithmetic average between maximum and minimum value will be considered as the standard case value.

3.3.4 Wheel flats

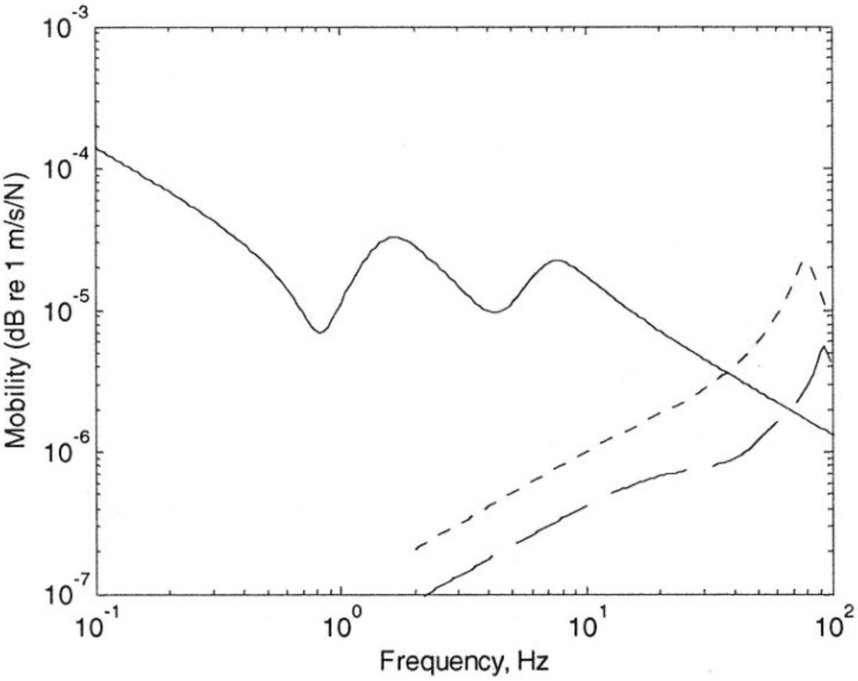
A vehicle related issue that needs to be addressed is the presence of wheel flats. In tread braked rolling stock, wheel flats are to some extent common. It depends on the implementation of wheel flat detection systems, vehicle recognition systems and adequate maintenance (wheel reprofiling) what the actual frequency of occurrence of wheel flats will be. Wheel flats can represent a significant source of ground borne vibrations. The issue of wheel flats and their impact to ground borne vibrations is treated in detail in WP 2. Reference is made to the deliverables in that WP for further explanation.

For new vehicles, which are to be measured against a standard specification, wheel flats should be avoided. As newly homologated vehicles are the subject of task 1.4, we will exclude them from the further work in this task. When assessing the vibration performance of a vehicle however one should take into account whether or not the vehicle design under concern is likely to develop wheel flats. An objective criterion for this assessment will be subject of further study in task 1.4

4. OUTLOOK TO FURTHER WORK

4.1.1 Dynamic excitation

Following [1] we express the dynamic excitation of the vehicle track system in terms of the mobilities (inverse real part of the impedance) of both vehicle and track/subsoil system. The following graph is copied from [1] and presents the mobilities for a reference situation, which is well within the range of the parameters presented in the previous sections.



Graph 2. Point mobilities of vehicle and track for the “reference situation”, from [1]

Vehicle ——, Track— —, soft rail pad - - - -

The graph demonstrates, that from 1 Hz upwards, and up to approximately 15 Hz, the mobility of the vehicle is dominant. Above 15 Hz, the track/subsoil becomes more important. In the highly relevant frequency range between 15 and 70 Hz, track and vehicle both contribute. Above appr. 70 Hz the track finally takes over and becomes the dominant component.

Making the track stiffer would press the track/subsoil curve down, so that the vehicle would be dominant for a wider range of frequencies. Note that the curves in graph 2 reflect a reference vehicle (30.000 kg mass) with reference speed (90 kph).

For vehicle configurations with a lower mobility over the relevant frequency range, the track/soil requirements would be more stringent for the vehicle to be the dominant component.

This consideration indicates the approach to be followed in the following sections:

- First, the question will be addressed to what extent vehicles exist, in real railway exploitation, with a mobility which is considerably lower than the mobility for the reference vehicle shown in graph 2. Here, it is probably sensible to make a distinction between freight vehicles and passenger vehicles, which we will do in the following sections. In order to assess the minimum likeable mobility for these two categories of vehicles, we will combine the values of vehicle parameters that will result in the lowest mobility value, without ignoring the requirement that the resulting set of parameter values must always reflect a realistic case.

- Second, once the extreme values of the vehicle parameters are set, a modified graph 2 will be produced in order to derive the required track parameter values such that the vehicle mobility is dominant over a sufficiently wide frequency range.
- Third, the set of track parameter values thus derived will be analysed and converted into a specification for a realistic track/soil combination, which is then to be described in a concise way to serve as the specification for the standard test track.

In order to answer the above questions, four different situations are distinguished:

1. The reference test track is intended to test the vibration performance of newly designed vehicles against a requirement in the procurement phase. In that case, the vehicle has probably a minimum performance which can be expressed as a low mobility over a certain frequency range (less mass controlled than the reference vehicle in graph 2). For this particular case a very low mobility track would have to be designed.
2. The reference test track is intended to test the vibration performance of in service vehicles, excluding freight cars, i.e. it will test the performance of the vehicle against an infrastructure requirement that can be met by a good quality maintenance of the vehicle (wheel maintenance, suspension maintenance, anti sliding provisions). In this case, the vehicle could have some fairly small shortcomings in terms of its vibration behaviour which would need to be detected on the test track. The track needs to be very good quality with fairly low mobility.
3. The reference test track is intended to test the vibration performance of in service vehicles, including freight cars, i.e. it will test the performance of the vehicle against an infrastructure requirement that can be met by a good quality maintenance of the vehicle (wheel maintenance, suspension maintenance). In this case, the vehicle could have some significant shortcomings in terms of its vibration behaviour which would need to be detected on the test track. The track needs to be fairly good quality with fairly low mobility.
4. The reference track is intended to test the vibration performance of in service vehicles, including freight cars, for drastic shortcomings in vibration performance, such as blocking primary suspension. The track can be a standard track.

4.2 PROPOSAL FOR FURTHER WORK

It is proposed to proceed as follows:

- Definition of the field of application of the test track method. The range of applications is to be developed into a range of test cases.
- Once the cases have been selected, modeling of the mobility of the vehicles to be tested shall be carried out,
- This will lead to conclusions about the maximum mobility of the test track to be designed,
- Once this reference track mobility has been defined, a set of corresponding parameters will be set, which will define the practical lay out of the test track.
- Then, a technical report (second deliverable) will be drafted by the partners in task 1.4

5. REFERENCES

[1] Triepaischajonsak, N., et al, Track based control measures for Ground Vibration, Proc. 10 IWRN,

[2] Project RIVAS, Del 5.1 State of the Art inventory report on vehicle parameters, October 2011

[3] Project RIVAS, Del 3.2, Results of the Parameter Studies and Prioritization for Prototype Construction for Ballasted Track, RIVAS_SNCF_WP3_D3_2_V3.0, 27 February, 2012

[4] Project RIVAS, Del 3.3, Results of the parameter studies and prioritization for prototype construction for slab track, RIVAS_BAM_ WP3_D3_3_V04, 15 May, 2012