The Durability Project - Report for the final data

5. draft 23 January 2006 by Kai Sørensen

Introduction and conclusions

In a durability test of a road marking material, the material is applied on to a surface in order to form a road marking, which is then subjected to exposure and the values of some characteristics are measured. In a road trial or a road test, the material is applied on to a road surface and exposed to wheel passages in combination with weather and climate. In a wear simulator trial, the material is applied on to a test plate and exposed to wheel passages.

The characteristics are those defined in EN 1436; i.e.:
- the coefficient of retroreflected luminance R_L
- the luminance coefficient under diffuse illumination, Qd,
- the luminance factor, β
- the chromaticity co-ordinates x, y
- the skid resistance measured by the skid resistance tester, SRT

The results of a durability test are values of the characteristics after exposure to certain numbers of wheel passages. For road trials, the period corresponds to one or two climatic cycles.

The question that has often been raised is if different test sites will provide the same results, when the number of wheel passages is the same. This question involves the further question, which is - are the values of the characteristics are determined by the wheel passages only or do other factors contribute either directly or indirectly in interaction with the number of wheel passages. Climate and weather, road surface texture and other factors have been mentioned as possible factors.

The lack of answers to these questions has been an obstacle to agreements concerning durability testing in connection with the introduction of CE-marking of road marking materials.

The purpose of the durability project is to seek answers to these questions. The organisation of the project has been that some suppliers of materials have volunteered to supply different materials for use in the project, while some test houses have volunteered to contribute with test sites.

Six different materials have been made available, of which one is a paint to be applied in two different thicknesses, so that the total number of materials/applications is seven. The test sites include 15 road trials sites, two wear simulators and two centre line road tests. At most test sites, application of some of the materials and/or measurement of some of the characteristics was omitted.

In addition to the values of the characteristics, the test houses have been asked to supply data concerning the roads, road surfaces, applications, climate, traffic, wheel passages, climate and weather.

The materials, trial sites and applications of materials are accounted for in chapter 1, while the presentation, use and quality of the final data is accounted for in chapter 2.

The final data has been made available in an Excel file.

Based on, amongst other things, the comparison of values for materials and repetitions of the materials, it is concluded that the data is of a sufficient quality and does contain information.

The chromaticity co-ordinates x, y meet the requirements for white road markings given in EN 1436 in all cases - at least as averages for the different wheel passages. This data is thought not to provide much additional information and has not been given further consideration.

In order to address the above-mentioned questions, the sets of final values of the characteristics R_L, Qd and β have been subjected to analyses by means of simple depreciation models. The general assumption is that a characteristic has an initial or potential value, from which is subtracted a term given by the product of a sensitivity and a load.

The sensitivity values are individual for the different materials, while the load values are individual for the different transverse locations at road trials - or after certain numbers of wheel passages at wear simulators. The values are determined so that the model values of the characteristic fit as well as possible to the actual final values.

The principles of the models are explained in chapter 3 and in some more detail in annex A.

> NOTE: The terms sensitivity and load are used throughout the report. These terms belong with model descriptions of the final values. The terms can be correlated with physical properties of the materials or actions by wheel passages or weather, but do not directly indicate such properties or actions.

The SRT values have also been subject to model analyses, refer to section 4.3 and to details given in annex E. Perhaps a bit surprisingly, the SRT values do seem to contain information, but they do not conform to the group divisions of test sites introduced for the other characteristics. It is suggested that the simple depreciation models are not applicable to the SRT, which can be expected to show more complex variation with the load than just depreciation from a high value.

In view of the model analyses, the above-mentioned questions have been reformulated into three questions:

1. Do different trial sites give roughly equal relative marks to the materials ?
2. Do different trial sites cause roughly equal relative marks to the different characteristics ?
3. What factors determine the loads so that the loads at different trial sites can be predicted and compared ?

The first question is investigated by the comparison of the sensitivity values of the different materials while the second question is investigated by means of the load values for the different characteristics. This is described in chapter 4, while details for the individual characteristics R_L, Qd and β are described in annexes B, C and D respectively. The analyses based on Qd and β provide similar results, which is reasonable as the two characteristics both are measures of reflection during daylight or under road lighting. The measured values of Qd and β show a fairly strong correlation.

The first two questions have to be answered in the negative, at least in general. However, for road trial sites within some groups, the answers can be positive. These replies are partly based on statistical tests, and partly on an engineering type of judgement of what differences would be acceptable in practice.

The third question is approached by comparing the loads - as determined in the models - to wheel passages. This is done in chapter 5.

For those cases, where wheel passages are known (five road trials and the two wear simulators), it is shown that the loads increase from initial values with the number of wheel passages in a linear manner.

The initial values may be attributed to factors like weather and winter maintenance - perhaps in interaction with wheel passages. The increase may be attributed to the action of the wheels - perhaps in interaction with other factors.

The linear relationship is not in general the same for the different trial sites. However, road trials within the above-mentioned groups show to a reasonable degree of approximation the same relationship between loads and wheel passages. This confirms the groups of road trials for those road trials where wheel passages are known.

In almost all cases, the average number of wheel passages can be calculated or estimated, so that average loads can be compared to average numbers of wheel passages. Some particular features, for instance high loads compared to the numbers of wheel passages, may be assumed to confirm the groups of road trials.

The general conclusions as based on data for R_L, Qd, β and wheel passages are:

I. the data collected in the project are useful
II. test sites do not in general provide the same results
III. within some groups, road trials can be expected to provide the same results
IV. the wear simulators do not belong to any of these groups
V. the wear simulators do not form their own group

The road trials in Belgium, France, Poland and the UK form a group A. The two road trials in Denmark, with longitudinal and transverse applications, are limiting cases for membership of the group, deviating in some respects.

For these road trials, the loads are medium compared to the number of wheel passages. Additionally, the R_L values of the paints show high sensitivities to the loads. The reason may be a relatively high erosion of paints on road surfaces with pronounced surface texture as reflected by medium to high values of texture depths.

The road trials in Finland and Sweden form a group B. The road trial site in Sweden is a co-operation between Norway and Sweden, where conditions are considered to be the same.

For these road trials, the loads are high compared to the number of wheel passages. Additionally, the thin materials - the paints and the tape - have high sensitivities to the loads. These observations can be explained by erosion by studded tyres during winter.

Membership of group A might have been expected for the road trials in the Netherlands and the Czech republic, but some features of the results prevent this:

- For the road trial in the Netherlands, the R_L values of the paints do not show high sensitivities to loads, but the Qd values do.
- The two road trials in the Czech republic, at the two sides of a two lane road, form their own group C with excellent agreement between the two road trials. The R_L values of the thinly applied paint show a very low sensitivity to loads.

These features may perhaps be related to less surface texture as reflected by rather low values of the texture depth.

The road trial in Austria might perhaps form a group together with other trial sites. However, thermoplastic materials were not applied on this road trial site and therefore the overlap in materials applied is too small to allow a decision on the issue.

Results from the road trial in Slovakia and from the centre lines on two roads in Spain have not been considered in detail due to the small amount of data.

The two wear simulators show low loads compared to the number of wheel passages. This feature together with other features make results different to those for the road trials. The reason is probably to be sought in the frequent roll over by wheels without exposure to weather and other actions. At the German wear simulator, the Qd values show very low sensitivities to loads for the paints; at the Spanish wear simulator this is not the case.

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1. Materials, trial sites and applications of materials

The materials that were made available for application are accounted for in table 1.1. The table also shows the product identifications that are used in the following.

Table 1.1: Materials made available for application.

<table>
<tr><td>Product identification</td><td>Producer</td><td>Product name</td></tr>
<tr><td>1. thermoplastic north</td><td>Cleanosol</td><td>Cleanosol 31 Exx</td></tr>
<tr><td>2. thermoplastic central</td><td>Prismo</td><td>Prismo life line 98/4</td></tr>
<tr><td>3. thermoplastic south</td><td>AETEC</td><td>F-2009 Thermospray "South Climate"</td></tr>
<tr><td>4. paint thin</td><td rowspan="2">SAR</td><td rowspan="2">Sinolack normandie 1RH329A</td></tr>
<tr><td>5. paint thick</td></tr>
<tr><td>6. tape</td><td>3M</td><td>Stamark 380SD</td></tr>
<tr><td>7. cold plastic</td><td>Pinciara S.P.A.</td><td>Polisignal R29 Bianco 4325</td></tr>
</table>

The roads used for the road trials are described in table 1.2.

Table 1.2: Roads used in road trials.

	road geometry	ADT	texture depth
Austria	two lane	7500	(asphalt)
Belgium	four lane	5200 **)	1,10 mm
Czech Republic	two lane	7200	0,38 mm
Denmark	two lane	5500 (8%)	1,00 mm
Finland	two lane	4500	1,35 mm
France	four lane	7550 (22%)	0,94 mm
Netherlands	four lane	36.000	0,56 mm
Poland	two lane	*)	0,65 mm
Slovakia	two lane	10400	0,44 mm
Sweden	two lane	2660 (19%)	1,40 mm
United Kingdom	four lane	17000	0,80 mm
*) no information so far **) estimated on the basis of wheel passages			

In Denmark, the materials were applied in both the longitudinal and the transverse pattern. These two applications are considered to form two different road trials distinguished as 'Denmark longitudinal' and 'Denmark transverse'.

In the Czech republic, the materials were applied in both sides of a two lane road. These two applications are considered to form two different road trials distinguished as 'Czech republic to Brno' and 'Czech republic to Ivanovice'.

Applications in the other countries are considered to form one road trial in each country distinguished by the names of the countries.

The total numbers of road trials is thus 13, although very limited use has been made of the data from the Slovakian road trial for the reasons explained in section 2.2.

Test sites of a different kind are the two wear simulators at BASt, Germany and at AETEC, Spain. The test plates used at the two wear simulators are 'BASt test plates'. However, additional texturized 'AETEC test plates' are used for some of the materials at AETEC.

Additional test sites are two roads in Spain, where materials were applied as centre lines. The roads are described in some detail in table 1.3.

Table 1.3: Spanish roads.

Roads	Traffic			Climate and weather			
	ADT	heavy traffic	vehicles on the centre line	T minimum	T maximum	Days with salt	Days with snow
Toledo	15049	30 %	22 %	-5 C	41 C	55	9
Soria	4500	30 %	7 %	-12,5 C	34,5 C	115	28

The applications are described in elaborate reports from some test sites, while little or no information is available from other test sites. The following mistakes are known to have happened:

- At the German test sites, the actual amounts of paint applied to the test plates are approximately 50% to high, this effectively turning the intended thin application into the thick application, and the intended thick application into a very thick application.

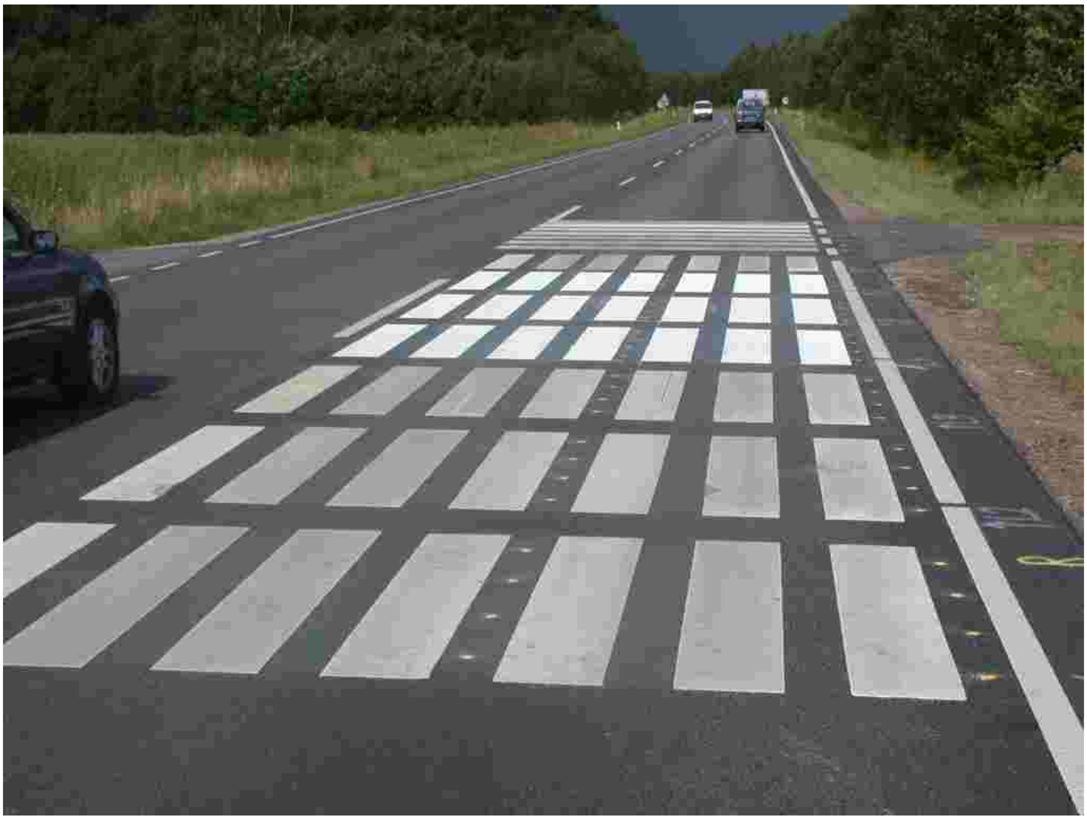


Figure 1.1: Example of a trial site with application in both the longitudinal and the transverse pattern (Denmark).

2. Presentation, use and quality of the final data

2.1 Presentation of the final data

The final data is available in an Excel file.

Each of the road trials contributes with a table of final values for each of those characteristics R_L, Qd, β, x, y and SRT that has been measured at the particular road trial. A table has an entry for the materials applied at that road trial and an entry for the transverse position on the road. In case more than one value was measured in different longitudinal positions, the value in the table has been formed as the average of those values along the road.

With the exception of one road trial, where all seven materials were applied, different selections of the materials were applied at different road trials. For some of the road trials or materials, the values have not been measured in all transverse positions, or they have been deleted because of heavy erosion. A single criterion has been used for deleting actually measured values - that the measured R_L value is less than 40 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$. This criterion has been applied for all the characteristics and all the road trials, but has been relevant only for the road trials of Denmark, Finland and Sweden.

At some road trials, the number of transverse positions used for measurement was reduced for one or more of the characteristics. The corresponding table is reduced accordingly.

An example of a table is given in table 2.1. In this case, each value is the average of three values measured in different longitudinal positions.

Table 2.1: Table of Qd values ($mcd{\cdot}m^{-2}{\cdot}lx^{-1}$) from the Danish longitudinal road trial.

Transverse position from edge	Material						
	1	2	3	4	5	6	7 [1)]
25 cm	115	117	130	2)	126	127	
75 cm	87	88	102	2)	2)	112	
125 cm	120	125	149	150	162	143	
175 cm	122	123	143	149	154	138	
225 cm	91	91	105	2)	2)	113	
275 cm	107	109	124	2)	161	125	
325 cm	114	116	127	2)	184	2)	

1) this material was not applied
2) these values have been excluded

Each of the two wear simulators contributes with a table as shown by an example in table 2.2. The transverse positions are replaced by measurement after different numbers of wheel passages. The initial values, before any exposure to wheels, are not included. The criterion to delete actually measured values - that the measured R_L value is less than 40 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ - has also been applied for the wear simulators, but is relevant only for the German wear simulator.

At the Spanish wear simulator, the materials were applied on 'BASt test plates', but additionally two of the materials (the paints 4 and 5) were also applied on 'AETEC test plates'.

The values measured for these additional test plates are handled as if they have resulted from additional materials in excess of the seven standard materials.

Table 2.2: Table of Qd values (mcd·m^{-2}·lx^{-1}) from the German wear simulator.

Number of wheel passages	Material						
	1	2	3	4	5	6	7 [1)]
100 000	203	194	219	286	278	254	
200 000	177	180	212	285	252	256	
500 000	[2)]	202	229	281	266	272	
1 000 000	[2)]	212	235	281	268	274	
1 500 000	[3)]	[3)]	[3)]	[3)]	[3)]	[3)]	
2 000 000	[2)]	218	242	[3)]	[3)]	273	
3 000 000	[2)]	215	238	[3)]	[3)]	273	
4 000 000	[2)]	214	242	[3)]	[3)]	251	

[1)] this material was not applied
[2)] these values were not measured or were excluded
[3)] these values were not measured

Additionally, each of the two Spanish roads contributes with a table, although with only one row, as the materials were applied only as centre lines.

Table 2.3 shows what materials were applied at the different trial sites. The numbering of the materials used in the table is used throughout the report.

Table 2.3: Materials and patterns applied.

materials	thermoplastic			paint		6:tape	7:cold plastic	repetition material
	1:north	2:central	3:south	4:thin	5:thick			
Road trials with longitudinal application								
Austria				×	×	×	×	5
Belgium	×	×	×	×	×	×		5
Denmark	×	×	×	×	×	×		1
Finland	×	×	×	×	×	×		1
Sweden	×	×	×	×	×	×		1
Road trials with transverse application								
Czech Republic	×	×		×		×	×	
	×	×		×		×	×	
Denmark	×	×	×	×	×	×		1
France	×	×	×	×	×	×		5
Netherlands	×	×	×	×	×	×		
Poland	×		×	×	×	×	×	5
Slovakia				×	×			
United Kingdom	×	×	×	×	×	×		
Wear Simulators								
Germany	×	×	×	×	×	×		
Spain	×	×	×	× ***)**	× ***)**	×		3
Edge lines at Spanish roads								
Road 1	×	×	×	×	×	×		3
Road 2	×	×	×	×	×	×		3

*) additional application on AETEC plates instead of BASt plates

Table 2.4 shows the number of values obtained for different transversal positions on the road trial sites, or after different numbers of wheel passages at the wear simulators. Where numbers are not filled in for a particular characteristics; this characteristic was not measured.

Table 2.4: Number of values.

	R_L	Qd	β	x, y	SRT
Road trials with longitudinal application					
Austria	6	6			6
Belgium	9	9			
Denmark	7	7	7	7	7
Finland	8		8	8	8
Sweden	6	6	6	6	6
Road trials with transverse application					
Czech Republic	15	15	15	15	15
	15	15	15	15	15
Denmark	7	7	7	7	7
France	31	31	31	31	3
Netherlands	16	16	16	16	2
Poland	3		1	1	2
Slovakia	1	1	1	1	1
United Kingdom	5	5	10	10	5
Wear Simulators					
Germany	7	7	7	7	7
Spain	10	10	10	10	8
Edge lines at Spanish roads					
Road 1	1				
Road 2	1				

2.2 Use and quality of the final data

For general information, the average values of the characteristics R_L, Qd, β and SRT are provided in figures 2.1, 2.2, 2.3 and 2.4 respectively. Figure 2.5 shows the chromaticity points for the average x, y values in the CIE chromaticity diagram.

The chromaticity points are all within the box for white road markings defined in EN 1436. For this reason the x, y values have not been subject to further investigation.

Because of the low number of values made available for the Slovakian road trial (two materials, each with one value for each characteristic), there has been no further use of these values.

It is apparent from figures 2.1, 2.2, 2.3 and 2.4 that the average values of R_L, Qd, β and SRT show considerable variation among test sites and materials. The individual values also show considerable variation among transverse locations on road trials or after exposure to different numbers of wheel passages on wear simulators.

Such variation can either be caused by significant uncertainty of the measurements or of the experiments themselves, including application and other sources of uncertainty.

Therefore, the quality of the data should be judged, among else by comparing measured values for a material with measured values for a repetition of the material at the same test site.

This is done in the diagrams of figures 2..6, 2.7, 2.8 and 2.9 for R_L, Qd, β and SRT respectively. The diagrams include all the available data of this sort for the trials sites.

The figures indicate good correlation, and this does promise some quality of the data. Accordingly, the values for these characteristics have been subject to 'model analyses' by a method introduced chapter 3. Details of the models are explained in annex A, and the results are introduced in annexes B, C, D and E for respectively R_L, Qd, β and SRT.

The models reflect an assumption that a final value is estimated by an initial or potential value, from which is subtracted a term which is the product of a sensitivity and a load. The models could be called 'depreciation models'.

The results of these model analyses are discussed in a more overall manner in chapter 4 with the view of seeking answers to two questions:
1. do different trial sites give roughly equal relative marks to the materials ?
2. do different trial sites cause roughly equal relative marks to the different characteristics ?

The questions reflect necessary criteria for accepting that different trial sites give equivalent results. The first question is investigated by means of sensitivity values and the second by means of load values.

It becomes fairly obvious that the SRT data - although the models seem to work fine - cannot be represented by simple depreciation models. The SRT data are therefore considered separately in section 4.3.

The Qd and β data give fairly similar results in terms of both sensitivity and loads. The two characteristics are normally not assumed to correlate strongly, but in view the above-mentioned finding it is interesting to test the correlation. This is done in figure 2.10 using data for those test sites, where both characteristics were measured. The correlation is only reasonably good.

A third question is:
3. what factors determine the loads so that the loads at different trial sites can be predicted and compared ?

This question is considered in chapter 5 by comparison of load values to numbers of wheel passages.

The model analyses do in themselves confirm some quality of the data. Simple assumptions regarding depreciation of the characteristic values lead to good correlation between measured values and values predicted by the model. This would not occur if the variation had mostly been caused by uncertainty.

As an example, the two Czech road trials are more or less duplications of each other at the two sides of the road. Nevertheless, the correlation between measured values at equivalent positions at the two road trials is not convincing (not shown). The model analyses provide the explanation that the positions are not really equivalent and show that the two road trials produce closely related results when this is taken into account.

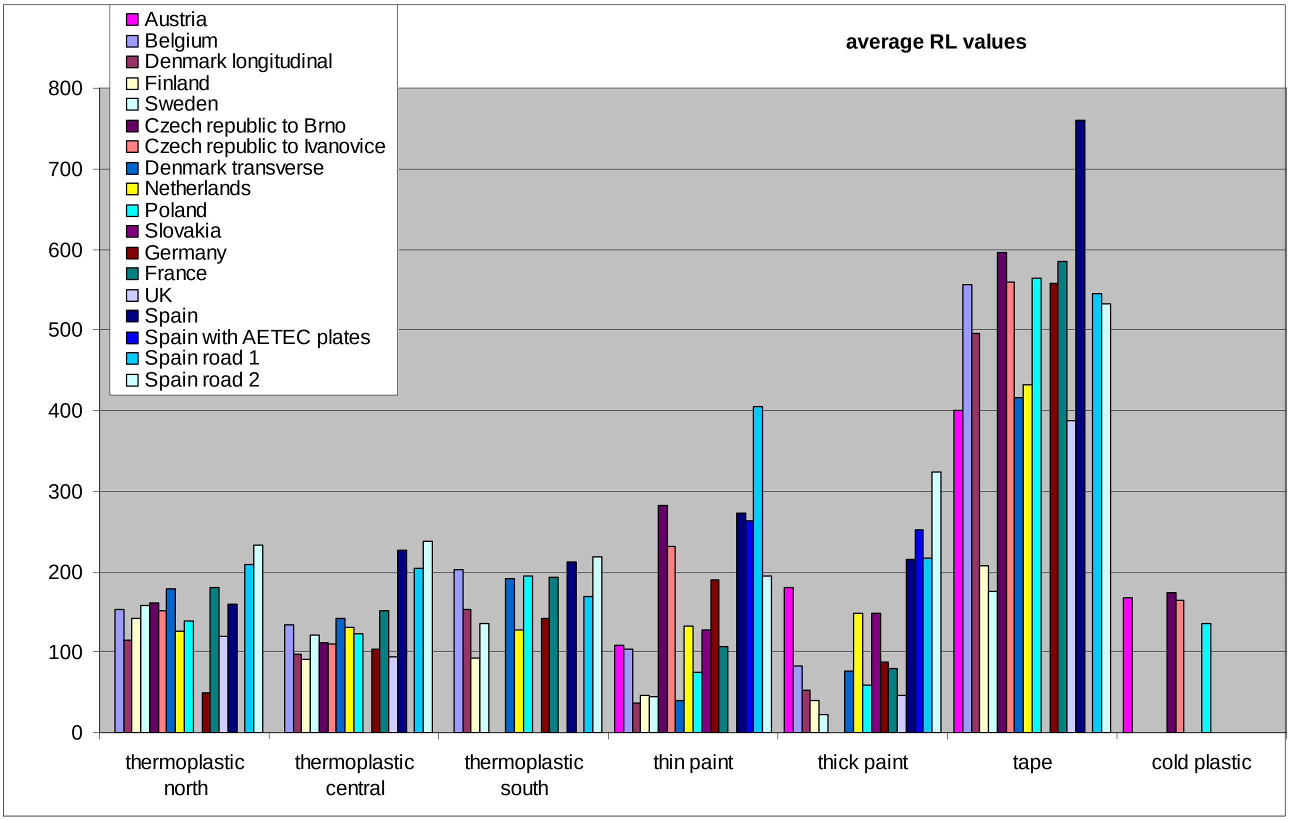


Figure 2.1 Average R_L values for the different materials and trial sites.

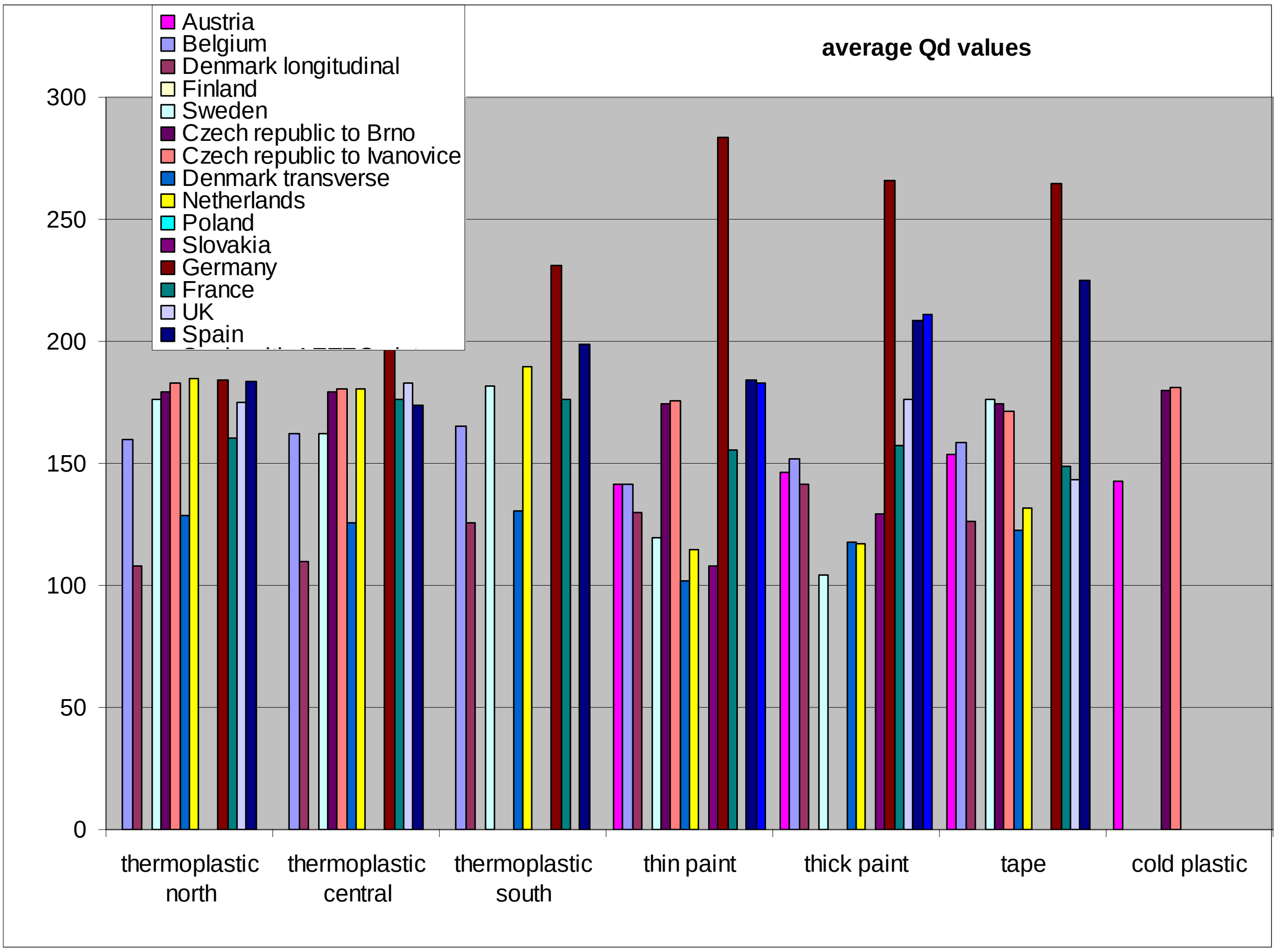


Figure 2.2 Average Qd values for the different materials and trial sites.

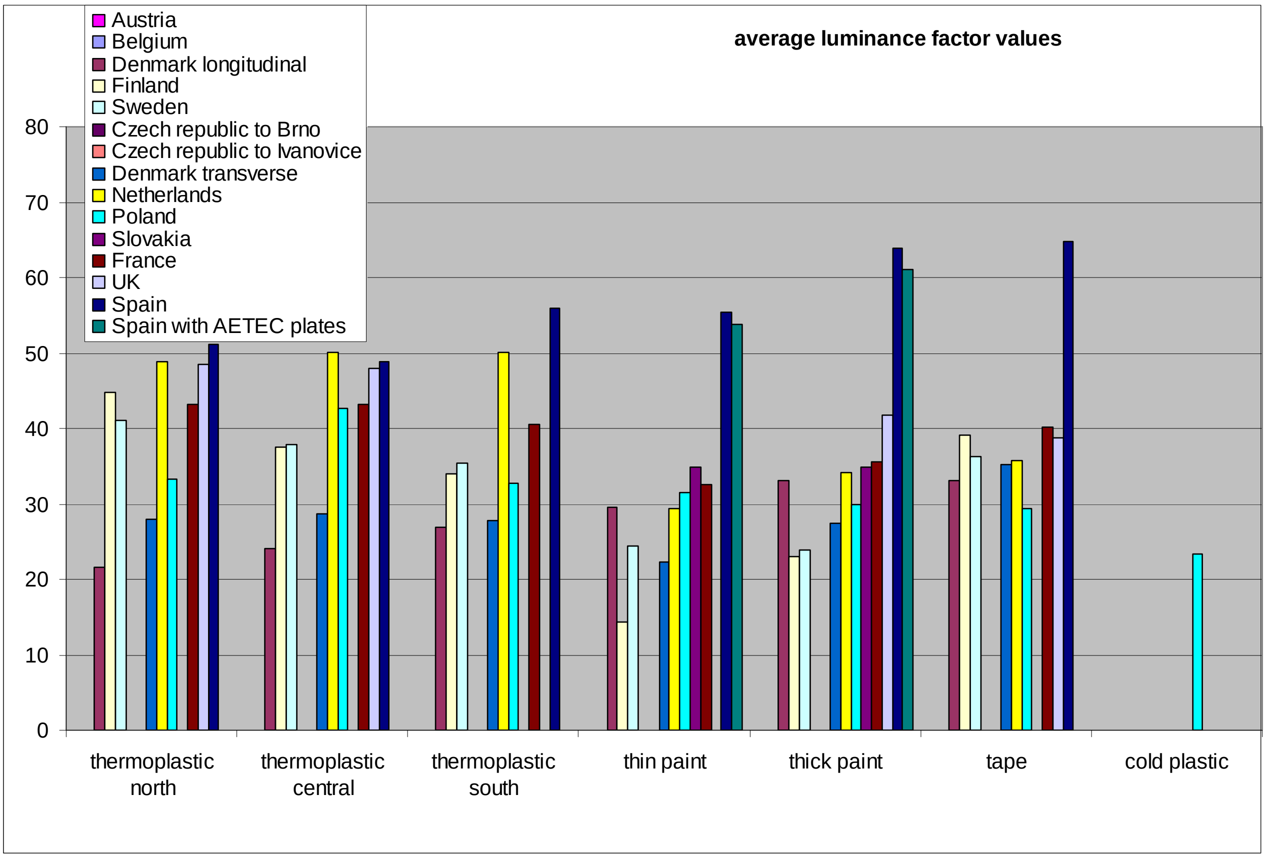


Figure 2.3 Average β values for the different materials and trial sites.

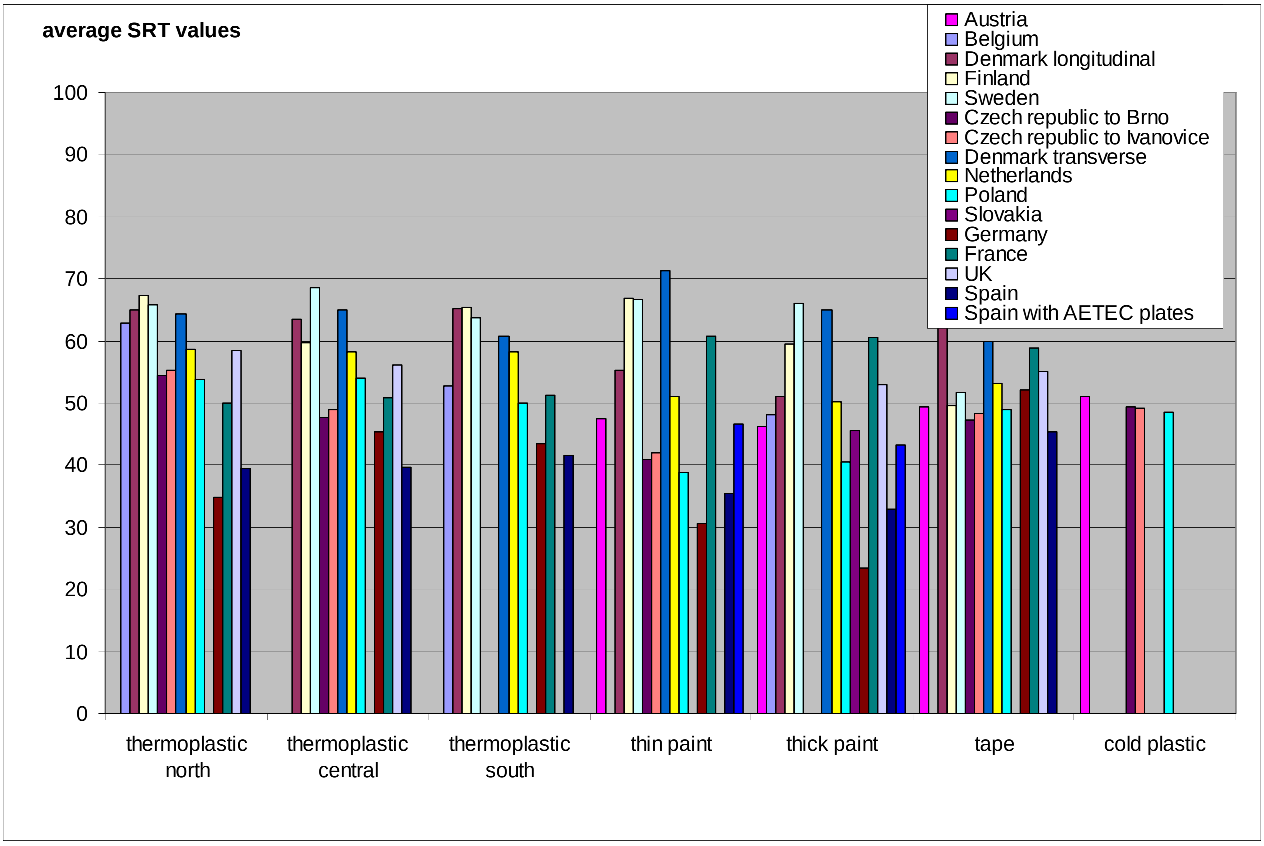


Figure 2.4 Average SRT values for the different materials and trial sites.

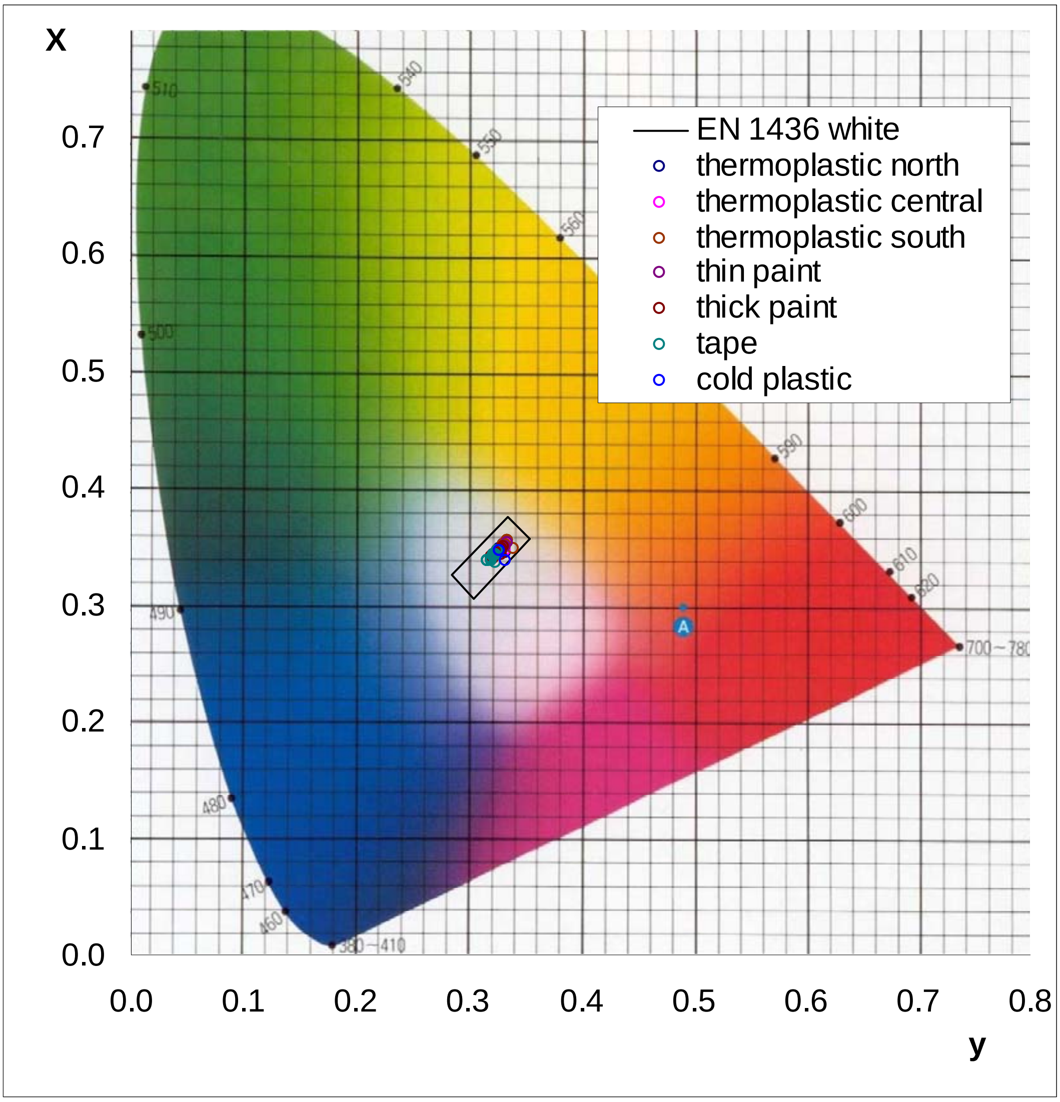


Figure 2.5: Chromaticity points for average chromaticity co-ordinates x, y.

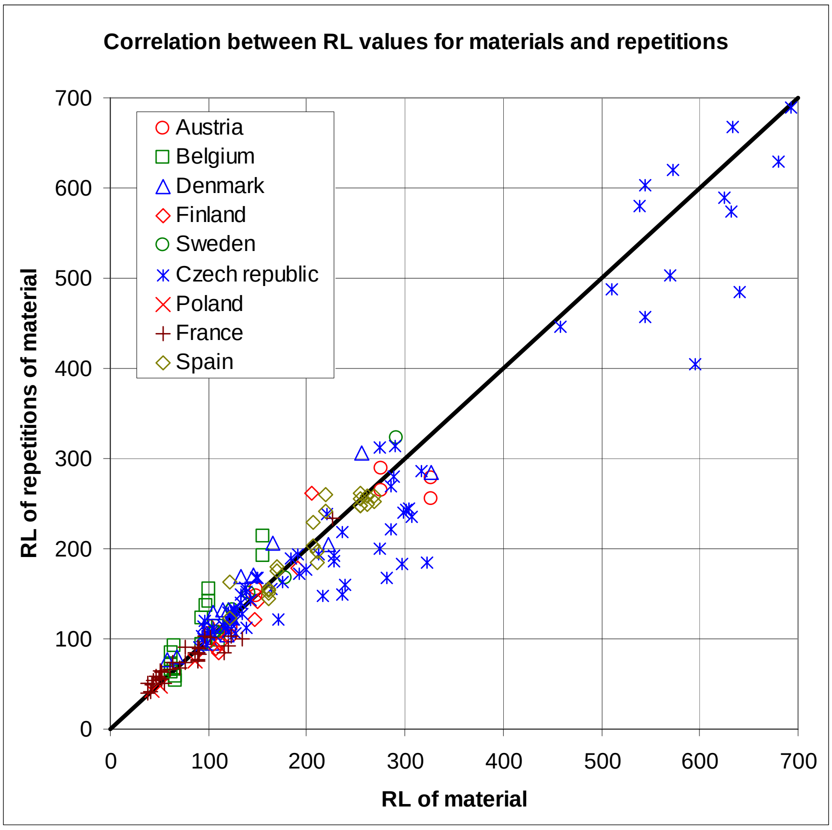


Figure 2.6: Correlation between R_L values for materials and repetitions.

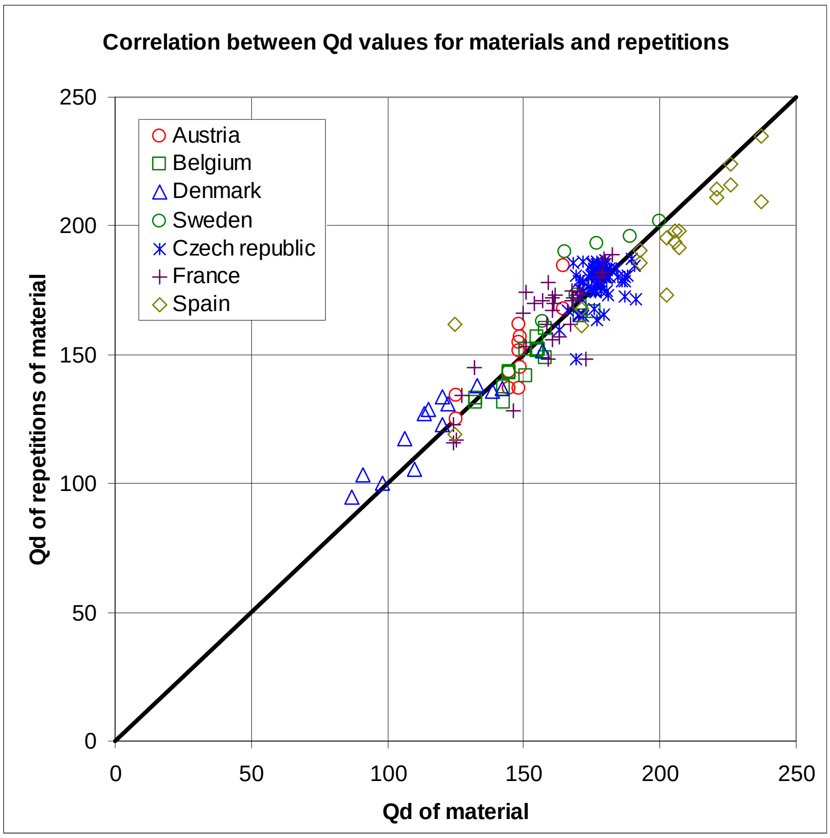


Figure 2.7: Correlation between Qd values for materials and repetitions.

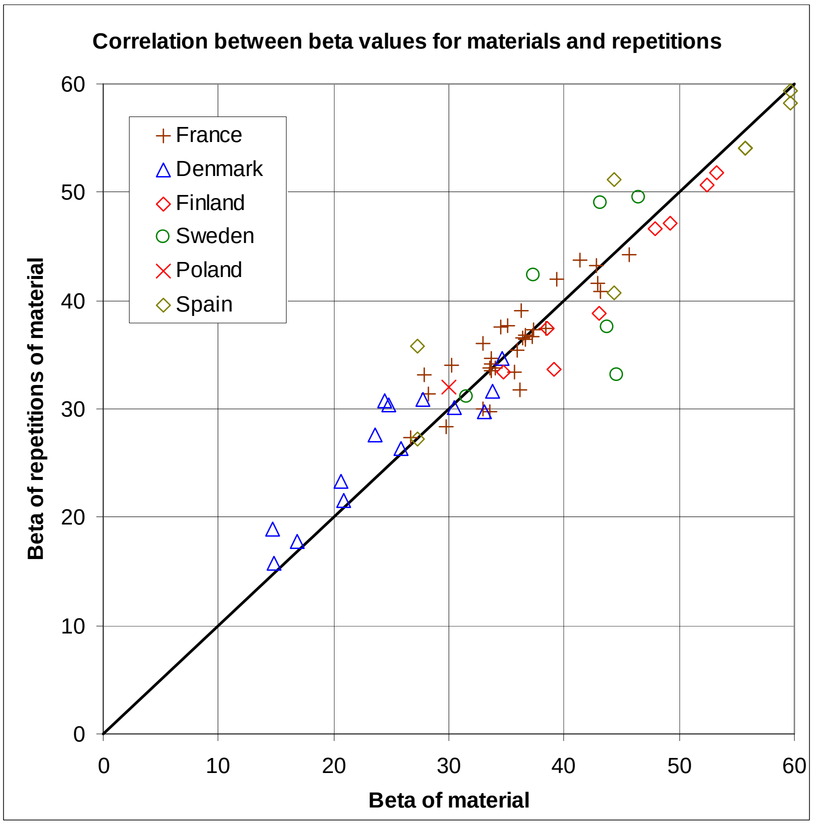


Figure 2.8: Correlation between β values for materials and repetitions.

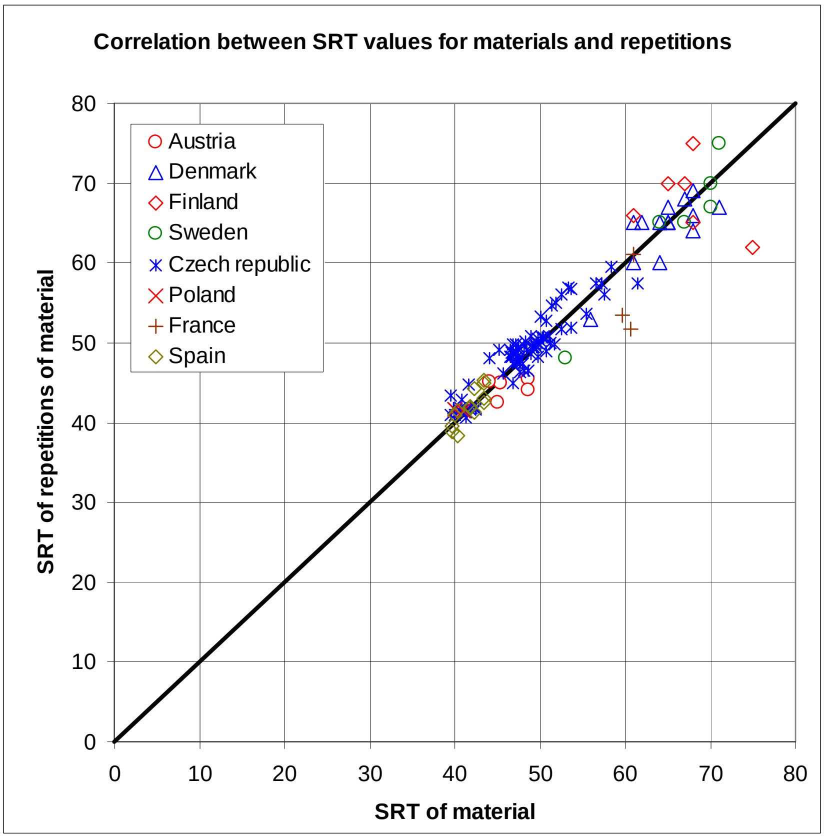


Figure 2.9: Correlation between SRT values for materials and repetitions.

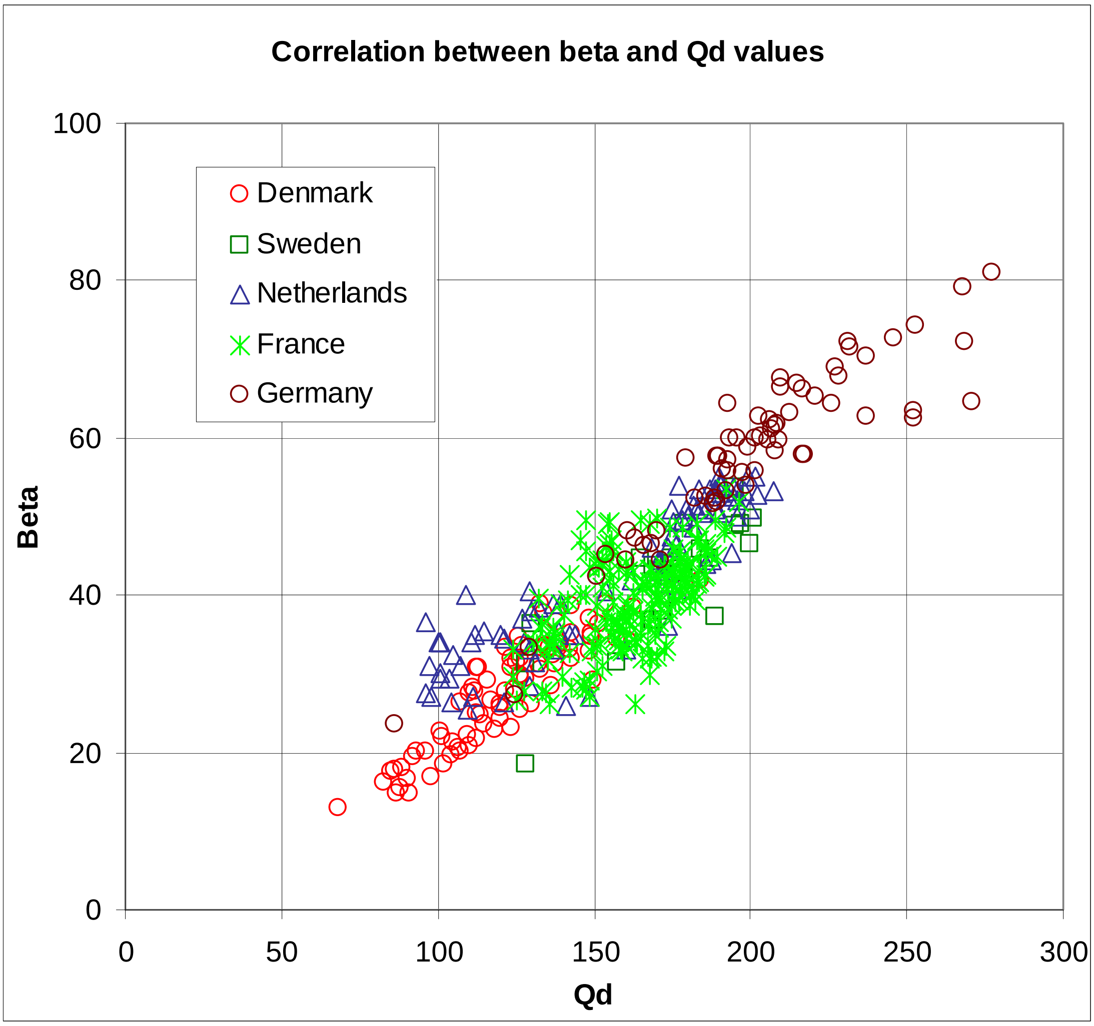


Figure 2.10: Correlation between Qd and β values.

3. Principle of models

3.1 Sets of final values

A characteristic is represented by a set of final values A made up of a table for each trial site as explained in section 2.1. The tables has an entry for the materials and another entry for the transverse position at road trials or roads - or the number of wheel passages at wear simulators.

3.2 Representation by sets of model values

For each characteristic, the set of final values A is represented by one or more sets of model values E that are obtained in model descriptions. Each of the values of E is assumed to be a potential or initial value from which a term describing depreciation is subtracted; this term itself being the product of a load and a sensitivity:

$E = I - L \times S$, where I is the potential or initial value, L is the load and S is the sensitivity

The values of I are set to pre-selected values intended to reflect reasonable initial or potential values, while the values of L and S are determined in such a way that the model values fit as well as possible to the final values (by minimising the sum of square deviations).

The use of model values E instead of direct inter-comparison of final values A brings some advantages.

Firstly, the quality of a fit between E and A values has some information about the validity of the assumptions behind the model. In particular, if one model causes a much better fit than another model then the assumptions behind the first model can be assumed to be more sound than the assumptions behind the second model.

Secondly, the model separates the depreciation of the characteristic value into two terms (load and sensitivity), so that the two terms can be studied separately.

Thirdly, the model results in the values of the loads L so that these can be correlated to and perhaps explained by various factors like wheel passages.

These advantages have been used to study the data in steps corresponding to some questions that have already been mentioned in section 2.2.

The first question is if different trial sites will give roughly equal relative marks to the materials. If one trial site results in a high mark to one material and a low mark to another material, while marks are opposite at another trial site, then the two sites differ from each other in an essential manner.

This question relates to the competition between producers of different materials - and to the applicability of different materials. The producer of a material may prefer testing at test sites where his material is promoted compared to other materials. At the same time, his material may be best suited for those practical conditions that are reflected by the test site (like climate, type of road surface etc.).

The question is investigated in section 4.1 by means of the values of the sensitivity S.

The second question is if different trial sites will cause roughly equal relative marks to the different characteristics. If one trial site results in a high mark to one characteristic and a low mark to another characteristic, while marks are opposite at another trial site, then the two sites differ in an essential manner. This question is investigated in section 4.2 by means of the values of the load L.

The third question relates to what factors determine the loads so that the loads at different trial sites can be predicted and compared. This question in considered in chapter 5.

The model is described in more detail in annex A, with some survey given in the next section.

3.3 General information on the models

The sensitivity values S are scaled in such a way that their average is unity for the different materials. Because of this, the load values L carry the unit of the characteristic and reflect the average depreciation of the final value of a characteristic. The sensitivity values S, on the other hand, indicate the degree to which the depreciation is established for the particular materials.

> EXAMPLE: If the load to Qd is 80 $mcd \cdot m^{-2} \cdot lx^{-1}$ at a particular position at a road trial, then the Qd of the materials is on the average reduced by this amount at that position of the road trial. However, if the sensitivity of a material is 0,75 then the actual reduction for that material is only by 0,75×80 = 60 $mcd \cdot m^{-2} \cdot lx^{-1}$.

The initial or potential values I influence the values of S in the manner that an increase of the value of I for a particular material will lead an increase of the value of S for that material as compared to the values of S for the other materials. However, the inter-comparison of different models will not be affected, as the change will be the same for all models.

The initial values I also influence the values of L in the sense that a general increase leads to a general increase of L. In this way, the proportions of the values of L between different test sites are affected, but not the absolute differences.

The values of I are, therefore, not very important, but they should be realistic. The values of I could in fact be set so as to make E values fit A values even better. However, such a procedure causes values to drift away from realistic values without resulting in much improvement of the fit. Because of this, it was decided to fix the values of I for all applications to those provided in table 3.1.

Table 3.1: Initial or potential values used for the models.

Characteristic	Material No.						
	1	2	3	4	5	6	7
R_L ($mcd \cdot m^{-2} \cdot lx^{-1}$)	300	300	300	300	300	900	300
Qd ($mcd \cdot m^{-2} \cdot lx^{-1}$)	250	250	250	250	250	250	250
β (0 to 100)	75	75	75	75	75	75	75
SRT (SRT units)	80	80	80	80	80	80	80

The models for R_L are in fact not formulated directly in R_L values, but in the logarithms of R_L values. Without particular preference, the natural logarithm $\ln(R_L)$ with the base e = 2,7183 has been used.

The consequence of this is that the model estimates of R_L are given by $\ln(R_L) = \ln(I) - L \times S$ or $R_L = I \times e^{-L \times S}$. This shows that the depreciation is not given directly in the unit of R_L, but as a factor $e^{-L \times S} = (1/e^{L})^{S}$, where $1/e^{L}$ is the average depreciation factor for the materials, and S tells the power to which this power this factor is applied to the different materials.

This formulation of models for the R_L has been chosen - instead of a linear representation - because of the large variations shown by R_L values, and because of the general understanding that uncertainty and reproducibility of R_L measurements and experiments is best presented on a percentage basis (which corresponds to factors). The matter is described in more detail in annex B.

The models for the other characteristics are formulated in the linear way as described above.

It is characteristic that the models for Qd and β lead to quite similar conclusions regarding sensitivities and loads. The reason is undoubtedly that both characteristics are measures of reflection in daylight or under road lighting, and that the values of both depend on the state of the surface - erosion and discolouring.

It is reasonable that the models for R_L, Qd and β are depreciation models with a high initial or potential value and gradual loss. The road marking surface results in much higher values than the underlying road surface, so that loss or depreciation of the road marking results in reduction of the value.

It is less clear how to handle the SRT as the road surface may well have a higher potential value than the marking material itself. It is also less certain how the SRT value depends on the marking material itself and how it is affected by wear and the underlying road surface. The complexity may well be much higher than reflected by a simple depreciation model.

However, the SRT has been incorporated by means of a high initial/potential value, assuming depreciation. The models do result in interesting conclusions, but the model assumption should not be taken to seriously. It might have been more realistic to assume a low initial/potential value and then a gradual build-up in proportion to the load.

4. Results of model analyses

4.1 Sensitivities of the materials for R_L, Qd and β

Based on annexes B, C, D and E the following models are considered:

I: the sensitivity values of the materials are the same at all test sites

II: the sensitivity values of the materials are individual at each test site

III: the sensitivity values of the materials are the same at test sites within groups, but individual between groups and at test sites not belonging to a group

The models include the characteristics R_L, Qd and β while the characteristic SRT is considered separately in section 4.3.

These models results in the average standard deviations provided in table 4.1.

Table 4.1: Average standard deviations for three models.

	model I	model II	model III
R_L (factor)	1,384	1,181	1,185
Qd ($mcd \cdot m^{-2} \cdot lx^{-1}$)	19,0	12,0	12,5
β (0 to 100)	6,04	3,46	3,73

Table 4.1 shows that the standard deviations are large for model I and much smaller for model II. The difference is highly significant for all three characteristics. Because of the smaller standard deviation for model II, the correlation between the measured values and the model values is much better for model II than for model I. This is illustrated in figure 4.1 for the R_L values. Similar diagrams can be found in annexes C and D for respectively Qd and β values.

The assumption underlying model I has therefore to be rejected. This relates to the first question raised in section 2.2 - if different trial sites will give roughly equal relative marks to the materials. The answer to this question has to negative - at least in general.

The groups of test sites considered in model III are:
A: the Belgian, French, Polish and UK road trials
B: the Finnish and Swedish road trials
C: the two Czech road trials

Table 4.1 shows that the standard deviations are slightly larger for model III than for model II. However, the increases are small for all the characteristics and not significant for any of these.

> NOTE: The test for significance is more sharp, when individual models are considered for the individual groups, refer to annexes B, C and D. This reveals one case - for β in group A - where the increase is just barely significant on a 95% level. However, the increase is small and to a small level; from 2,2 to 2,7.

This modifies the answer to the above-mentioned first question. Different trial sites may in some cases give roughly equal marks to the materials.

It is hardly surprising that the Finnish and Swedish road trials form their own group, separate from other road trials, in view of the heavy erosion by studded tyres during winter.

It is comforting that the two Czech road trials can form a group, actually with a strong similarity in results for all three characteristics.

In annexes B, C and D it is considered to include the two Danish sites into group A. The Danish longitudinal road trial fits regarding R_L values, and the transverse road trial regarding Qd and β values. These two test sites may be considered to be border cases, where perhaps some circumstances have prevented a clear adoption into the group.

The distributions of sensitivities show quite large differences, as illustrated in the diagrams of figure 4.2 for the R_L values. These diagrams have been ordered in a sequence that starts at the Finnish and Swedish road trials with high sensitivities for materials 4, 5 and 6 (thin materials - the paints and the tape) and ends with the wear simulators with high sensitivities for materials 1, 2 and 3 (the thermoplastics).

The Austrian road trial has not been considered for adoption into groups, because of little overlap regarding the selection of materials.

It is unfortunate that the Czech and the Netherlands road trials cannot be adopted into group A to form a large 'central European' group reflecting approximately the same climate. This matter should be explained in terms the road surface or other external factors.

The two wear simulators cannot be placed in a group together with any of the road trials. It is considered in annexes B, C and D that the two wear simulators can form their own group, but this is prevented by strong differences for the Qd values.

One can speculate about the causes of these differences. The high sensitivities for materials 4, 5 and 6 at the Finnish and Swedish road undoubtedly reflect heavy erosion of thin materials by studded tyres. The high sensitivity for materials 1, 2 and 3 at the wear simulators may reflect internal heating of the thermoplastics - in particular the soft material 1 - by the frequent passage of wheel.

Distributions for Qd and β values are similar to each other, but in some cases widely different compared to the distributions for the R_L values; refer to the diagrams in figure 4.3. The order of the diagrams is the same as in figure 4.2 for the R_L values.

The diagrams in figure 4.3 looks like a progression, which is broken by two cases.

The first case is the Netherlands road trial, where the sensitivity is large for materials 4, 5 and 6 (the thin materials).

The second case is the German wear simulator, where the sensitivities for the Qd of materials 4 and 5 (the paints) are negative, meaning that Qd values have been promoted by the load instead of showing deterioration. A comparison to the Spanish wear simulator shows why the two wear simulators cannot form a group.

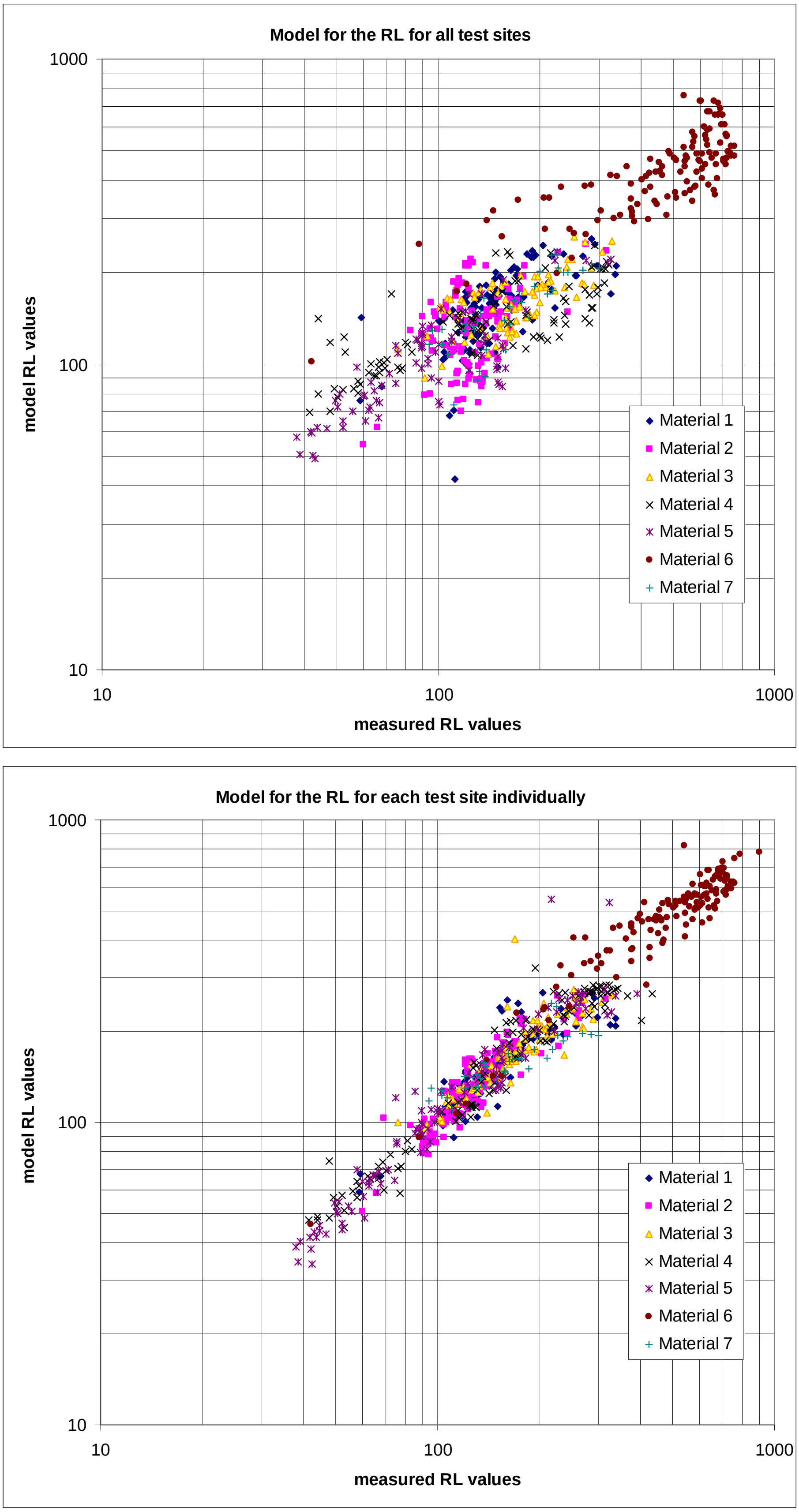


Figure 4.1: Correlation between measured and model R_L values for model I at the top and model II at the bottom.

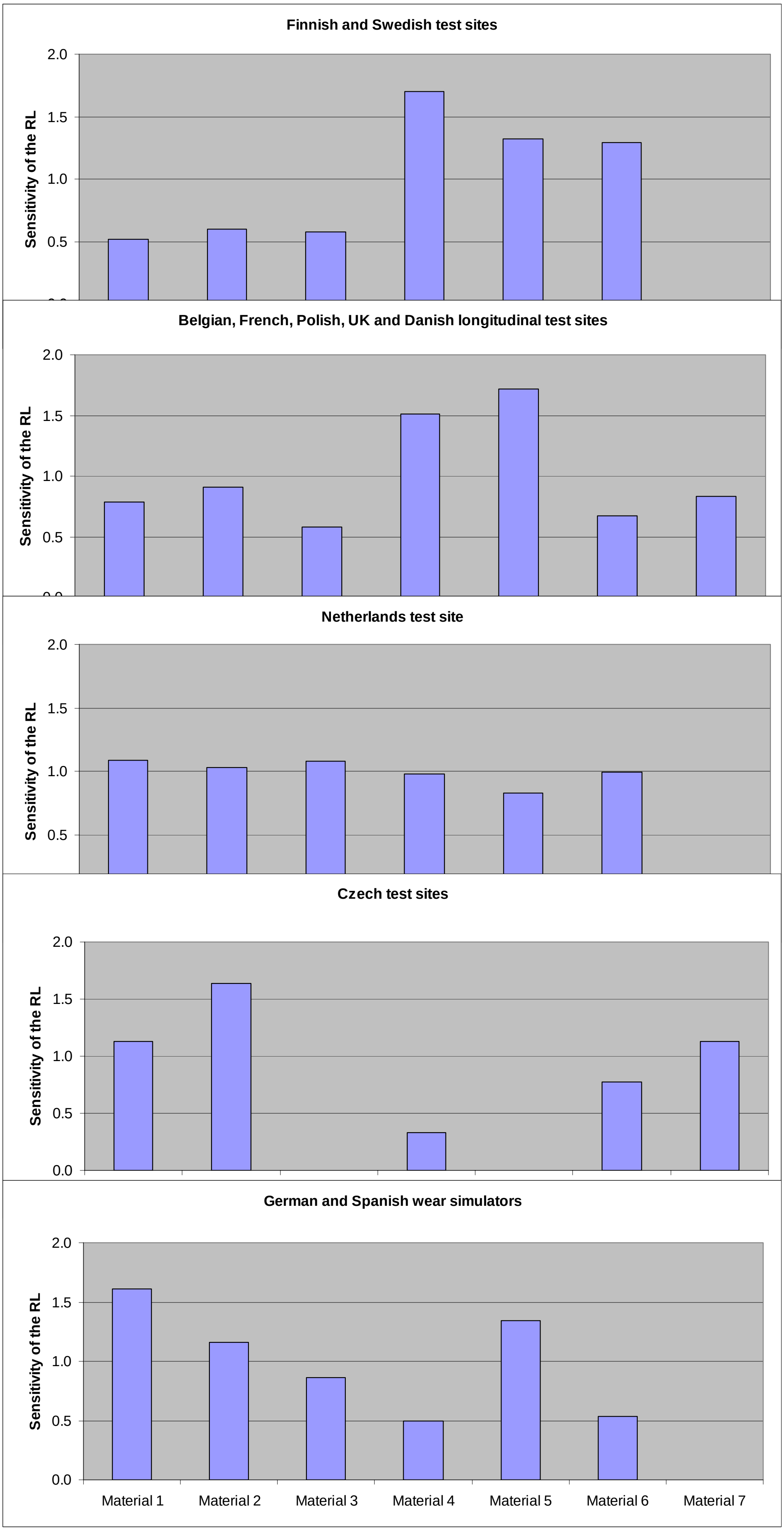


Figure 4.2: Distributions of sensitivities for R_L.

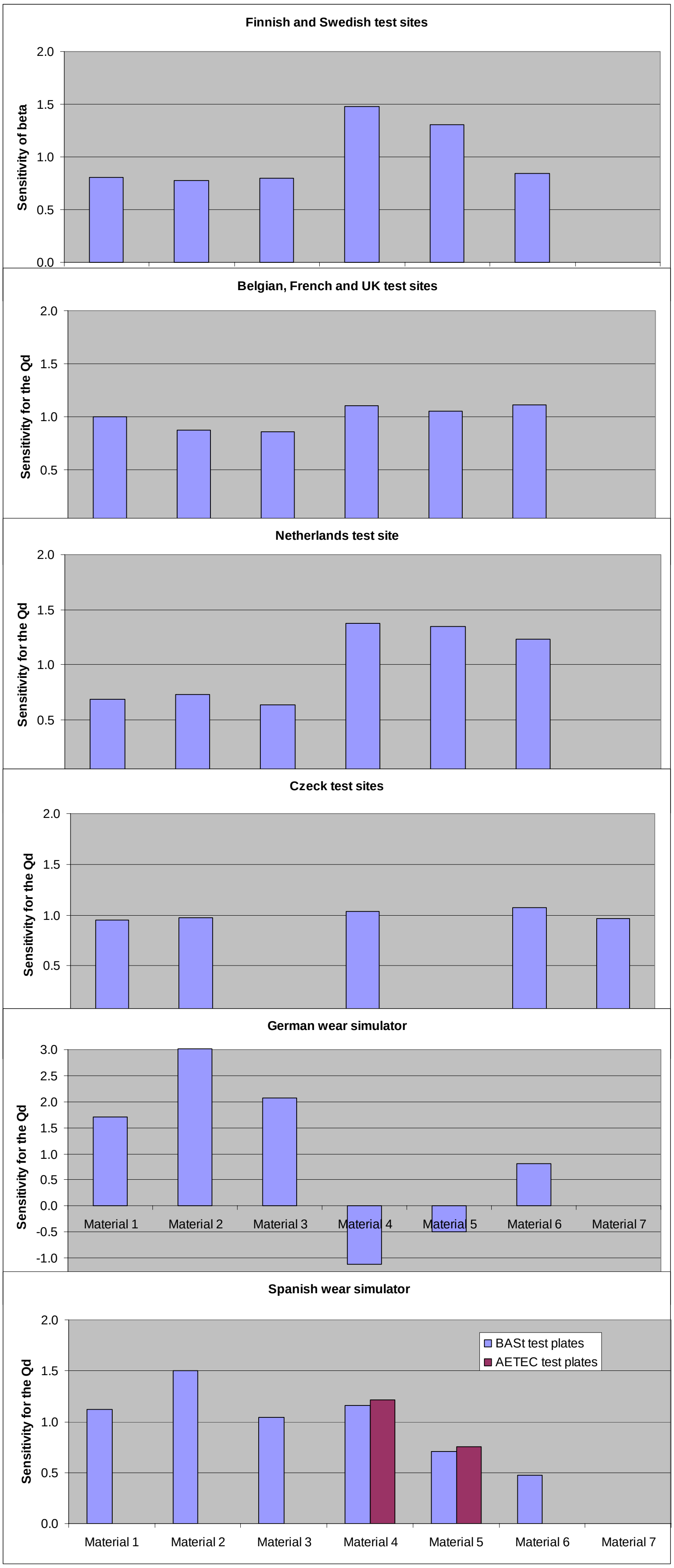


Figure 4.3: Distributions of sensitivities for Qd (β for the Finnish and Swedish road trials).

4.2 Loads at the test sites for R_L, Qd and β

The loads derived for the characteristics R_L, Qd and β are considered in the following, while the loads for the characteristic SRT are considered separately in section 4.3.

The average loads are shown in the diagrams of figure 4.4. These are informative in themselves, among else by indicating that the loads for Qd and β show similar variations among the test sites.

The scale of the loads is such that for each decrease in R_L by one percent, Qd will typically decrease by 1 $mcd \cdot m^{-2} \cdot lx^{-1}$ and β will typically decrease by 0,3. However, there are large deviations from this scale; in particular for the wear simulators.

The loads can also be studied in view of the second question raised in section 2.2 - if different trial sites will cause roughly equal relative marks to the different characteristics. In order to decide this question, some of the data has been rearranged in diagrams in figure 4.5 to show relative loads; i.e.: loads that have been rescaled to form an average of unity for each characteristic.

The answer to the question can be affirmative in those cases where the relative loads are fairly equal for the different characteristics. This matter is decided on an engineering type of consideration on what differences would be acceptable in practice; statistical tests have not been applied. It is most interesting to compare the average loads for test sites within the groups A, B and C introduced in section 4.1.

The diagram a in figure 4.5 shows that the road trials forming group A (Belgian, French, Polish, UK road trials, refer to section 4.1), including the Danish road trials, meet the above-mentioned criterion. One exception is the high relative load for R_L at the UK trial site.

The diagrams b and c show that the road trials in the groups B (the Czech road trials) and C (Finnish and Swedish road trials) also meet the criterion.

Therefore, the answer to the above-mentioned second question can be affirmative for road trials within groups.

The two wear simulators, on the other hand, show large differences in the relative loads. This is a reason, in addition to the differences in Qd sensitivity distributions, that the two wear simulators have not been made to form a group.

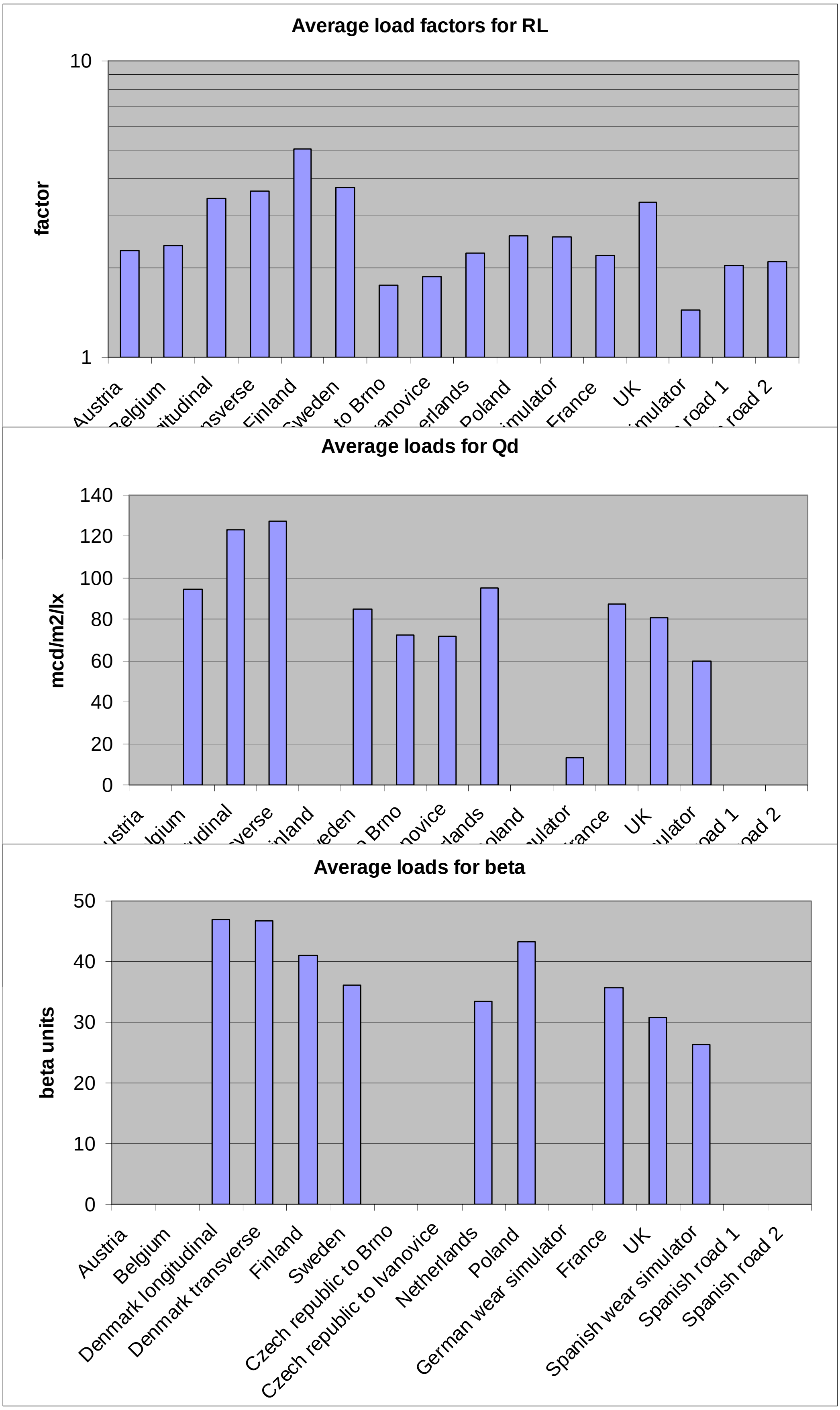


Figure 4.4: Average loads for the characteristics R_L, Qd and β.

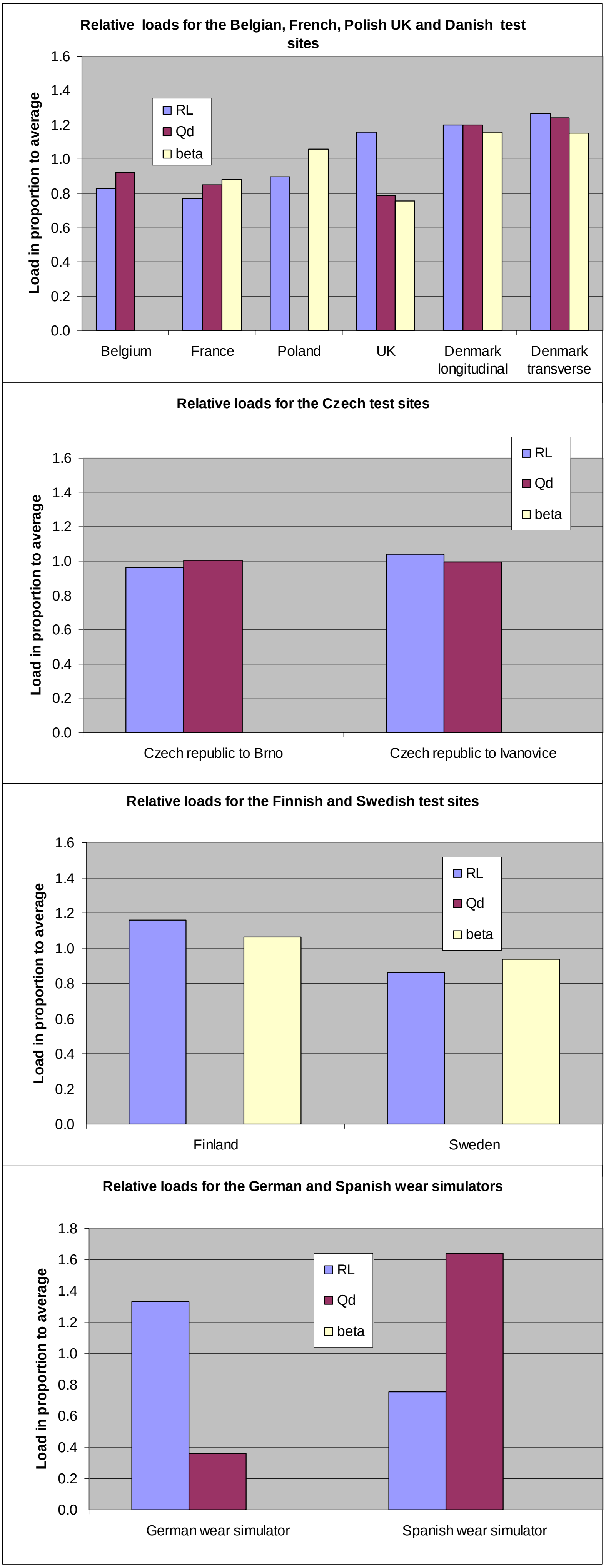
Figure 4.5: Relative loads for the characteristics R_L, Qd and β.

a: Group A and Danish test sites

b: Group B

c: Group C

d: wear simulators



4.3 Sensitivities and loads for SRT

The models discussed in annex E are depreciation models like the models used for the other characteristics of R_L, Qd and β. The following models are considered:

I: the sensitivity values of the materials are the same at all test sites

II: the sensitivity values of the materials are individual at each test site

The standard deviations obtained for models I and II are respectively 6,6 and 3,7 SRT units. The difference is highly significant.

The assumption underlying model I has therefore to be rejected and the answer to the first question raised in section 2.2 - if different trial sites will give roughly equal relative marks to the materials - has to negative. This is the same conclusion as reached for the other characteristics, which is therefore confirmed by the SRT data.

This type of model is considered as well:

III: the sensitivity values of the materials are the same at test sites within groups, but individual between groups and at test sites not belonging to a group

These models do not confirm the group division of test sites introduced for the other characteristics. The only group that is confirmed by the SRT data is the one formed by the two Czech road trials (group C), while other groups (A and B) fail the criterion that the distributions of sensitivities of the materials should be fairly equal. Refer to annex E for details.

The matter is probably that the simple depreciations models do not fairly describe how the SRT values depend on the load.

It is natural to expect that the other characteristics of R_L, Qd and β have the highest values in the initial state and that the values are depreciated with increasing actions. Micro beads are gradually lost and dirt accumulates in the road marking surface. Eventually, as erosion causes loss of the road marking surface, the much lower values for the road surface itself will influence the values.

Such an expectation does not apply for SRT values. These are often quite low for the initial state, but may increase with the actions. The value obtained by the road marking surface may well be influenced by the texture of the road surface. The value for the road surface may be higher or lower than for the road marking surface.

A complex behaviour is verified by figure 4.6, which shows the loads for four road trials sites as functions of the number of wheel passages in locations transverse to the road (these are the only road trials for which there is enough data for such a presentation). The trend lines added in figure 4.6 should not be taken seriously, but they do indicate varied behaviour.

It might be considered that SRT values are on the average not degraded by actions, but actually upgraded. This idea may be supported by the distribution of average loads for SRT values, which is shown in figure 4.7. This distributions of loads can be compared to the distributions for the other characteristics as shown in figure 4.4. It is seen that a low load for instance R_L often corresponds to a high load for SRT and vice versa.

As an example, the Spanish wear simulator shows the highest loads for the SRT of all test sites, but the lowest loads for the R_L.

Models for the SRT assuming upgrading with actions can be established by assuming low initial SRT values. Such models are not mentioned in annex E, but have been tried and do result in distributions of loads that are in more agreement with the distributions for the other characteristics. However, the groups of test sites based on the other characteristics are not confirmed.

It has to be concluded that the SRT value and its variation with loads is not a property only of the road marking, but also of the road surface and perhaps even the nature of the loads.

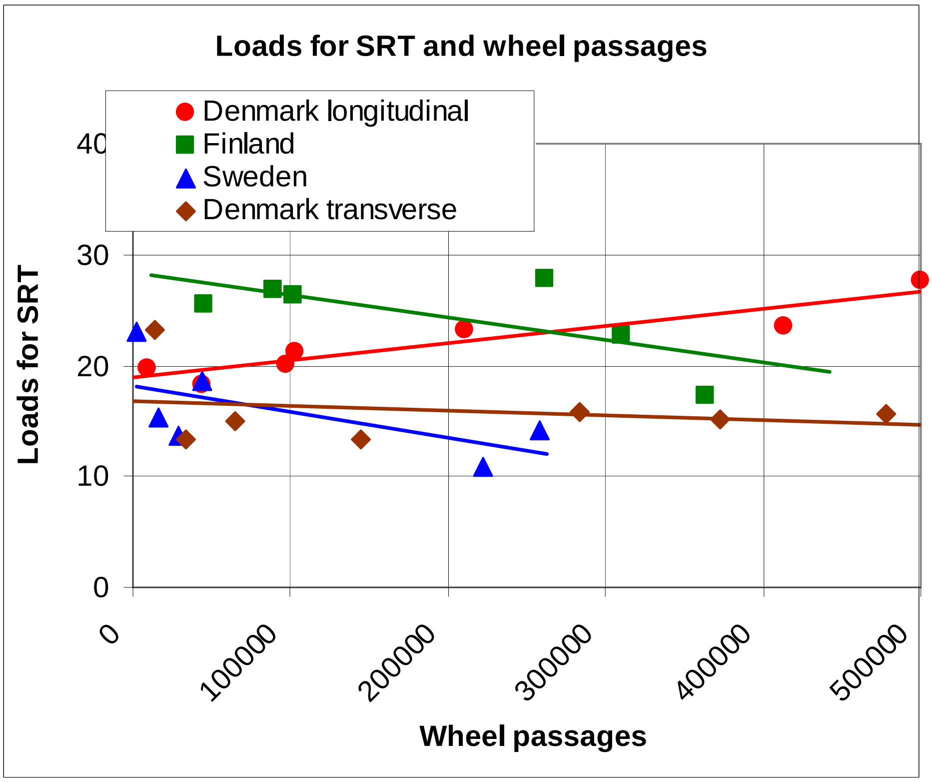


Figure 4.6: Loads for SRT and wheel passages.

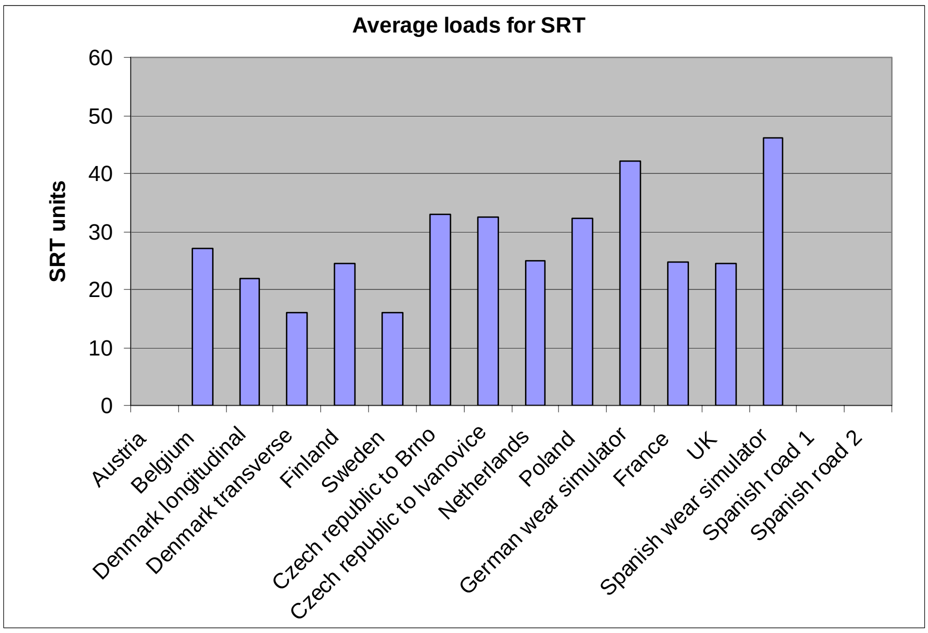


Figure 4.7: Average loads for SRT.

5. Loads and wheel passages

5.1 General

This chapter deals with the third question raised in section 2.2 - what factors determine the loads so that the loads at different trial sites can be predicted and compared. The question is approached in a number of steps.

The wheel passage distributions, as available for five of the road trials and the two wear simulators, are introduced in section 5.2.

These distributions are used for a detailed comparison of loads and wheel passages in section 5.3 seeking an answer to two questions:

a. which type of function will provide a good correlation and simultaneously reflect reasonable assumptions regarding the load provided by the wheels ?
b. should the wheel passages be represented by the simple sum for small and large vehicles, or should wheel passages by large vehicles be given larger weight (for instance counting as several wheel passages by small vehicles) ?

It seems that a simple linear relationship may account for the influence of wheel passages on loads. The slope of a line is a measure of the action of the wheels, which is clearly stronger at some trial sites than at others. The initial value of a line testifies a significant influence of other causes or actions (for instance weather and winter maintenance), which is also stronger at some trial sites than at others.

There is no obvious need for applying different weights to wheel passages by small and large vehicles.

In order to provide some information for those road trial sites, where the wheel passage distribution has not been supplied, a simple comparison of average loads and wheel passages is described in section 5.4.

This simple comparison verifies the finding in section 5.3 that loads are more strongly affected by wheel passages at some trial sites than at others. In this sense, the correlation between wheel passages and loads is poor in general. There is some indication that the correlation is better for road trials within the groups A, B and C introduced in section 4.1 than between trial sites in general.

It needs to be explained why wheel passages have different effects on the loads at different test sites. An explanation should be based on physical conditions, and should preferably also explain why different materials are affected to different degrees.

For the Finnish and Swedish road trials, the severe erosion by studded tyres does provide a good explanation. For the Danish road trials, one could speculate about winter conditions and winter maintenance, like moist weather, frequent salting and occasional snow ploughing.

It is interesting that the Netherlands road trials stand out in this respect and in other respects. A single particular feature might perhaps provide a single explanation.

The particular features of the wear simulators are probably lack of actions of weather and climate, and heating of some of the materials by frequent wheel passages.

The number of wheel passages may perhaps be used to describe the load when comparing results between road trials of the same group. However, the limited amount of wheel passage data prevents a clear conclusion.

5.2 Wheel passage distributions

Wheel passage distributions available from the road trials in Belgium, Denmark, Finland, France and Sweden are shown in figures 5.1, 5.2, 5.3, 5.4 and 5.5.

The distributions for Denmark, Finland and Sweden cover one lane of a two lane road, the distribution for belgium one lane of a four lane road, and the distribution for France two lanes of a four lane road.

The figures for Denmark, Finland, France and Sweden show wheel passages for small and large vehicles, and the sum. The figure for Belgium shows only the sum.

The distributions for Denmark, Finland and Sweden are in a much finer grid than used for measurement of the characteristics. The locations where the characteristics have been measured are indicated in the corresponding figures as well. The distributions for Belgium and France are for the same locations as used for measurement of the characteristics.

The distributions show some similarities, but also some differences. For instance, figure 5.5 for Sweden illustrates driving with more distance to the edge line than figure 5.3 for Finland.

Wheel passages are also available for the wear simulators in Germany and Spain (the distributions are not shown).

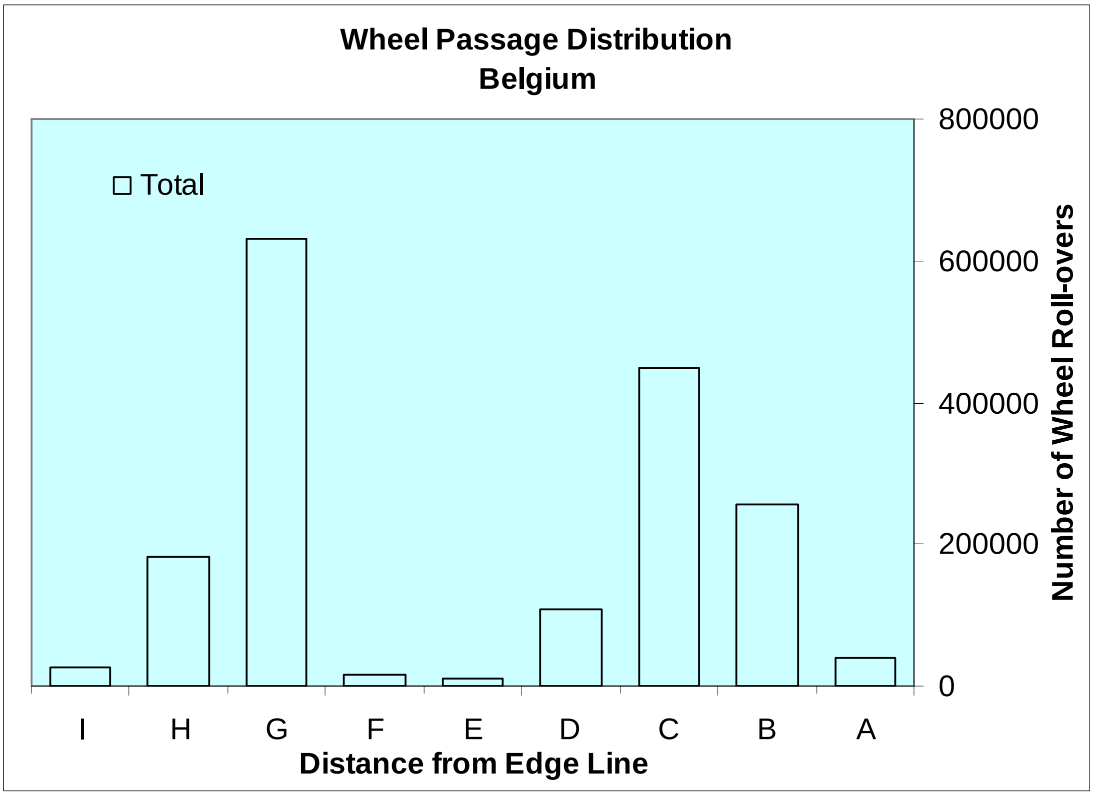


Figure 5.1: Wheel passage distribution for the Belgian road trial site.

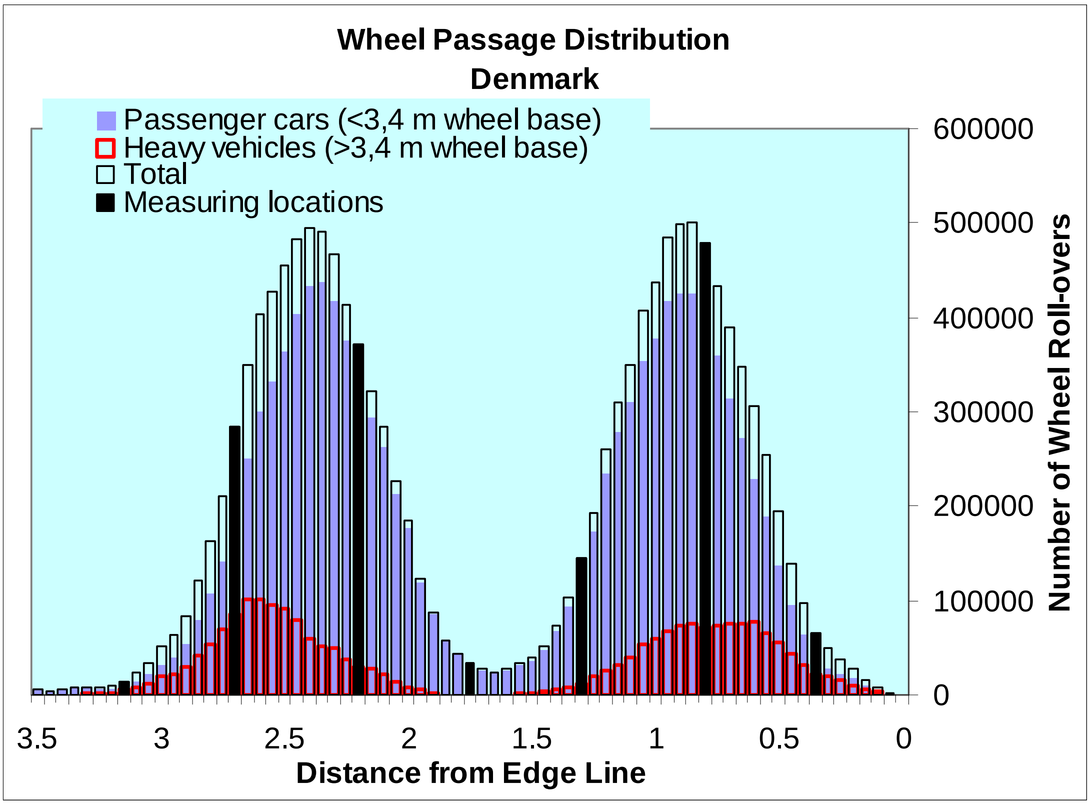


Figure 5.2: Wheel passage distribution for the Danish road trial site.

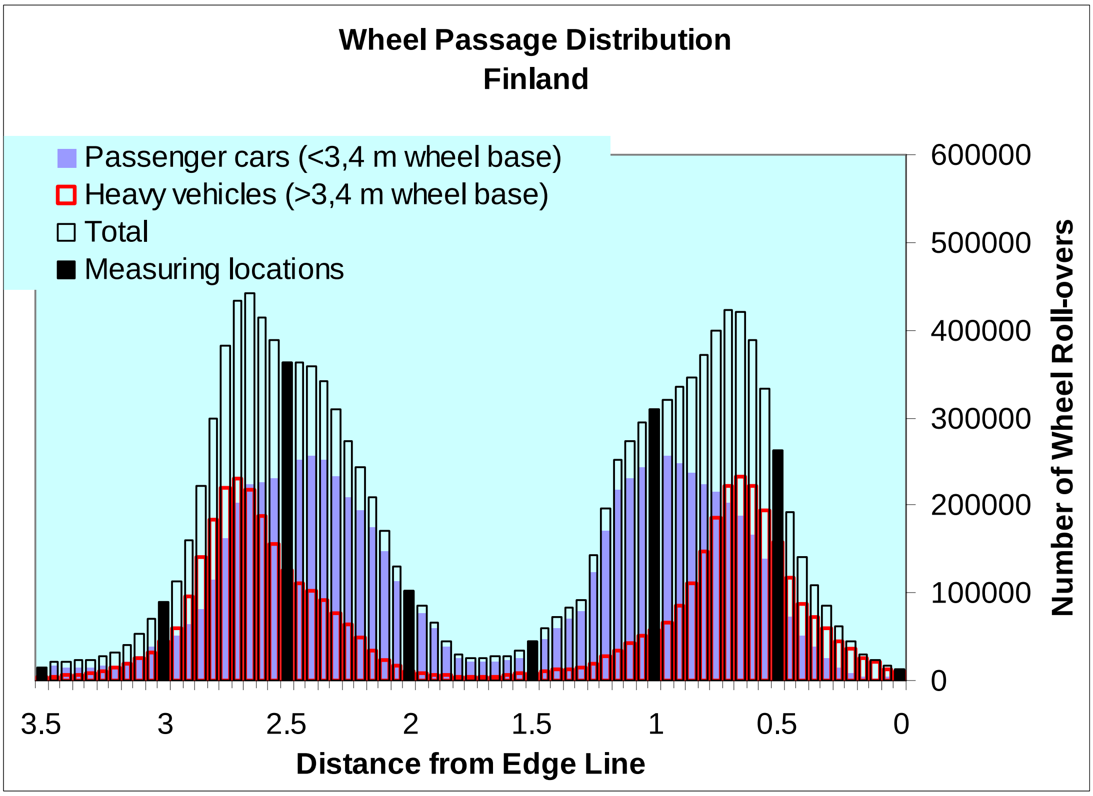


Figure 5.3: Wheel passage distribution for the Finnish road trial site.

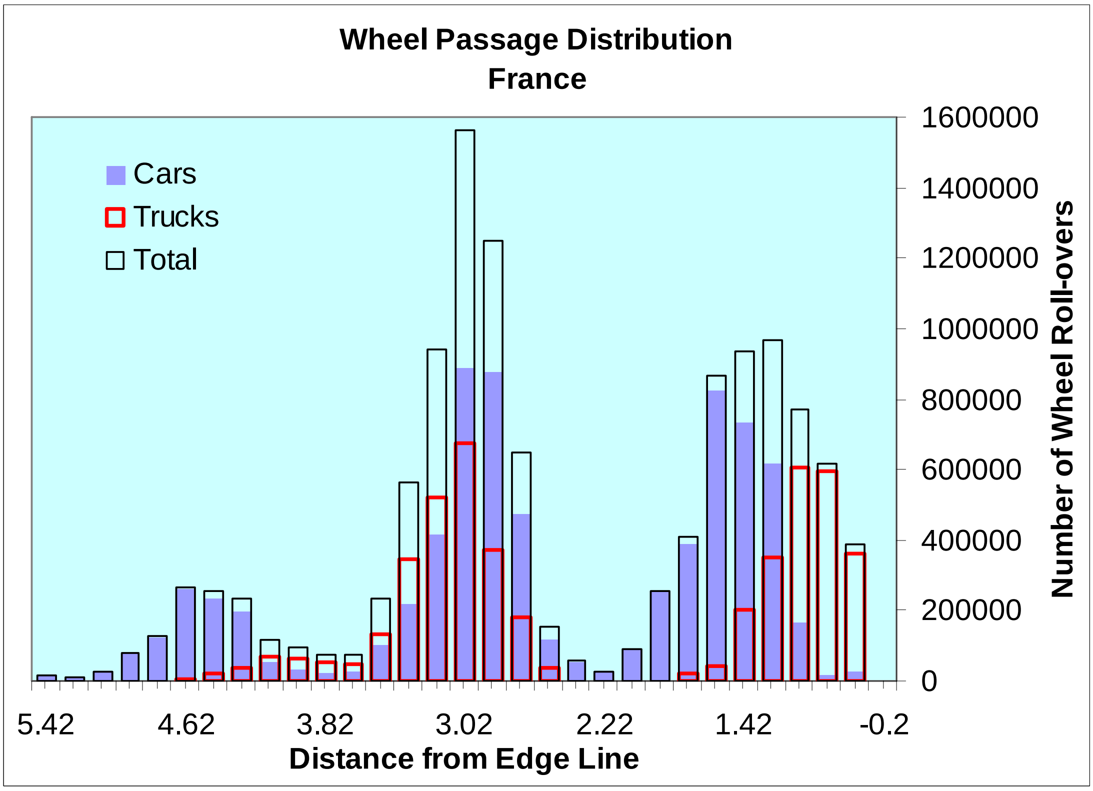


Figure 5.4: Wheel passage distribution for the French road trial site.

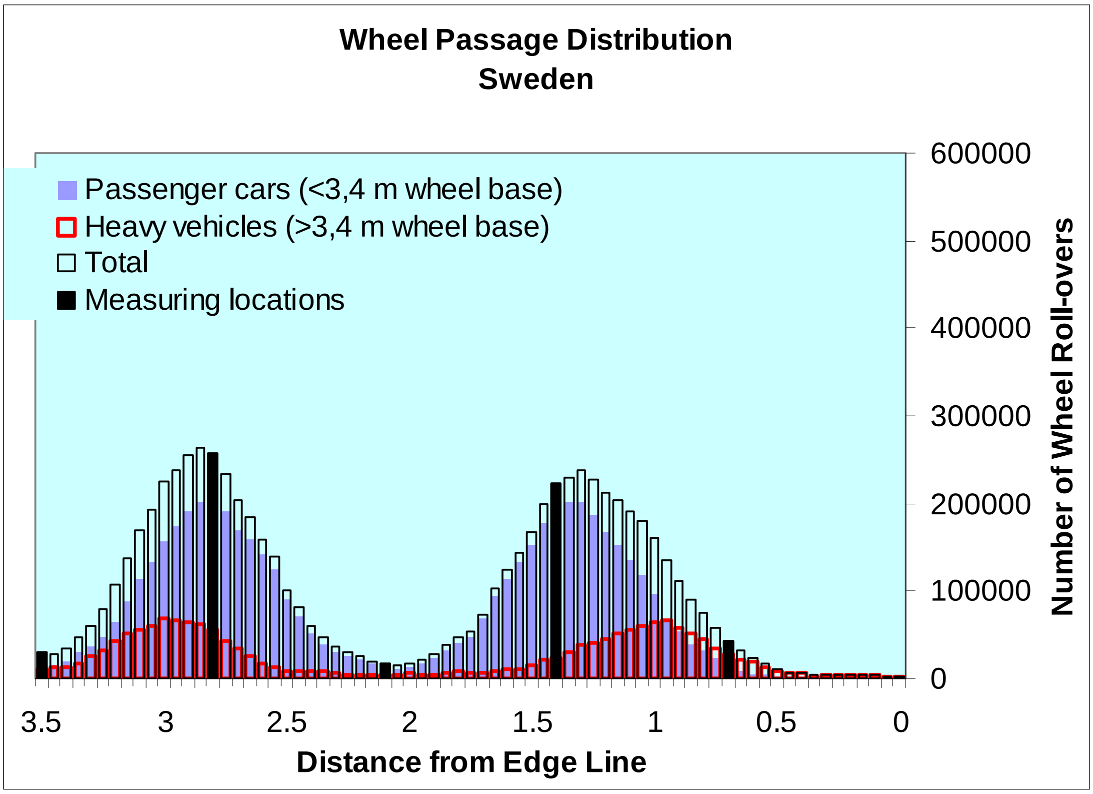


Figure 5.5: Wheel passage distribution for the Swedish road trial site.

5.3 Detailed comparison of loads and wheel passages

5.3.1 Transverse distributions of loads and wheel passages

Figure 5.6 shows diagrams for the French road trial site with distributions for the transverse location on the road for the numbers of wheel passages and for loads values for R_L, Qd and β.

> NOTE: Similar diagrams can be established for the road trials in Belgium, Denmark, Finland and Sweden, but the diagrams for the French road trial have been preferred because of the detailed measurements in fine steps across two driving lanes.

The striking feature is that the distributions have large similarities. This in itself indicates that the loads are correlated to some function of the number of wheel passages.

This raises two questions:

c. which type of function will provide a good correlation and simultaneously reflect reasonable assumptions regarding the load provided by the wheels ?
d. should the wheel passages be represented by the simple sum for small and large vehicles, or should wheel passages by large vehicles be given larger weight (for instance counting as several wheel passages by small vehicles) ?

The type of function considered in the following subsections 5.3.2 and 5.3.3 is one where the load is a linear function of the number of wheel passages; i.e.: load = $a \times N + b$, where N is the number of wheel passages, a is the slope of the line and b is the start load at zero wheel passages.

The load represents a loss of the value of the characteristic as an average for the different materials (refer to chapter 4). The assumption behind the linear function is, therefore, that the loss of the value of the characteristic is in proportion to the number of wheel passages. The slope of the line is a measure of the action of the wheels, which may be stronger at some trial sites than at others. The start load can be attributed to other causes or actions, for instance weather and winter maintenance - perhaps in interaction with wheel passages.

The test of a function lies in the scatter in a diagram with linear axes showing the load versus the number of wheel passages. For the linear function, the scatter is reasonably low, refer to the diagrams shown in the following subsections 5.3.2 and 5.3.3. In the diagrams, the linear functions are represented by linear trend lines.

Other reasonable functions could have been assumed. Diagrams have been constructed for a type of function corresponding to diagrams with a logarithmic axis for the numbers of wheel passages (not shown), but these turn out to have larger scatter.

It has been investigated to provide a weight to the passages of wheels on large vehicles, where the weight is in principle determined so as to minimize the scatter in diagrams as shown in the following subsections 5.3.2 and 5.3.3. This investigation has not been complete, but in no case did a weight provide a significant reduction of scatter. Therefore, it is assumed that wheel passages by small and large vehicles count equally, and the numbers of wheel passages used in the following are simple sums.

There is an uncertainty inherent in the comparison of loads and wheel passages, that there can be some offset between the locations of the loads (where the characteristics were measured) and the wheel passages (where the wheel passages were counted). As the wheel passages numbers show strong gradients, refer to figures 5.1 to 5.5, even a small offset can introduce additional scatter in comparison diagrams. Therefore, in a few cases where this seemed obvious, some data was brought into step in the diagrams shown in the following subsections.

Diagrams showing the actual values of the characteristics could of course have been used instead of the above-mentioned diagrams showing the load factors. Examples are provided in figure 5.7 and 5.8. However, the wealth of data would lead to a much higher number of diagrams and these would provide a less clear interpretation of the results.

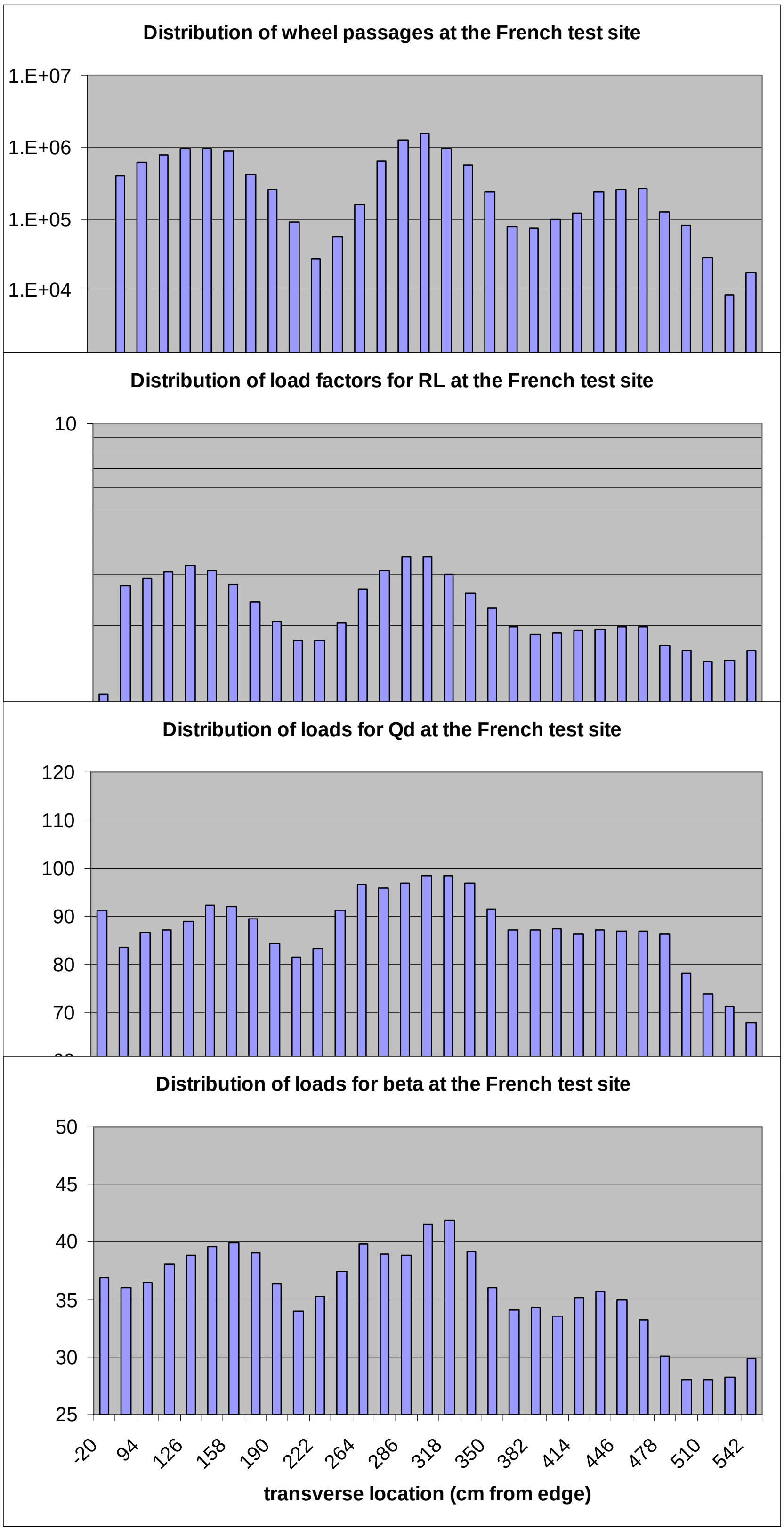


Figure 5.6: Distributions of wheel passages and loads for R_L, Qd and β.

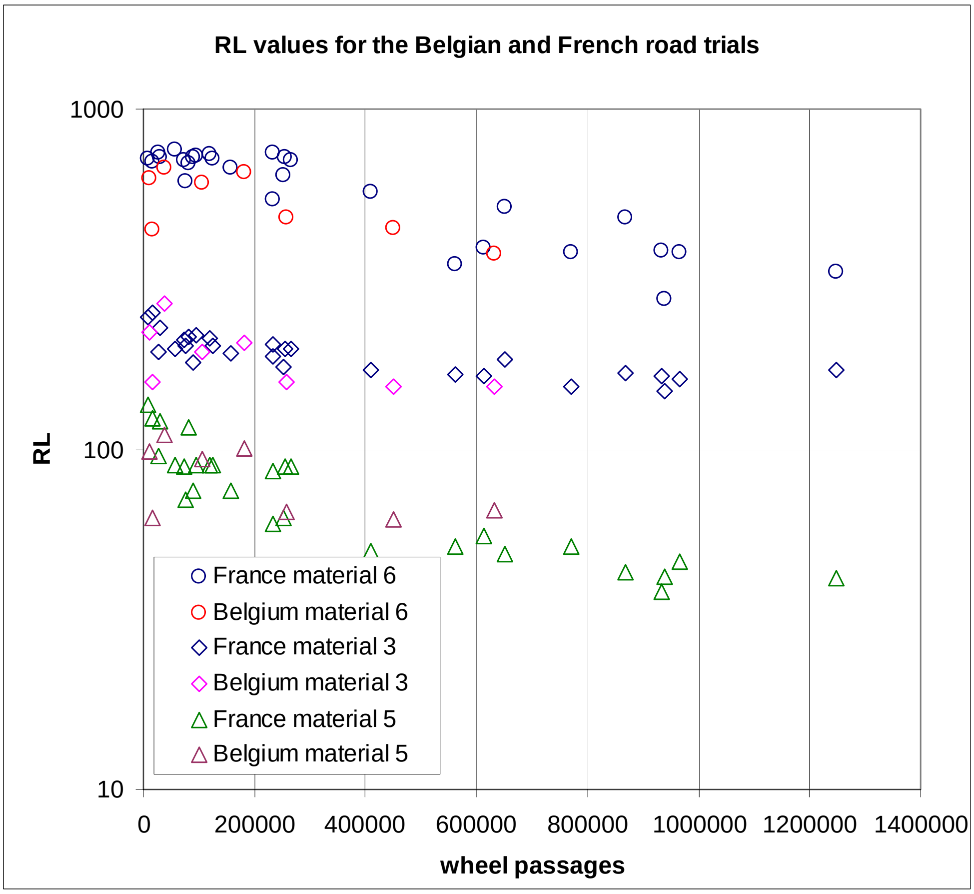


Figure 5.7: R_L values for the Belgian and French road trials versus wheel passages.

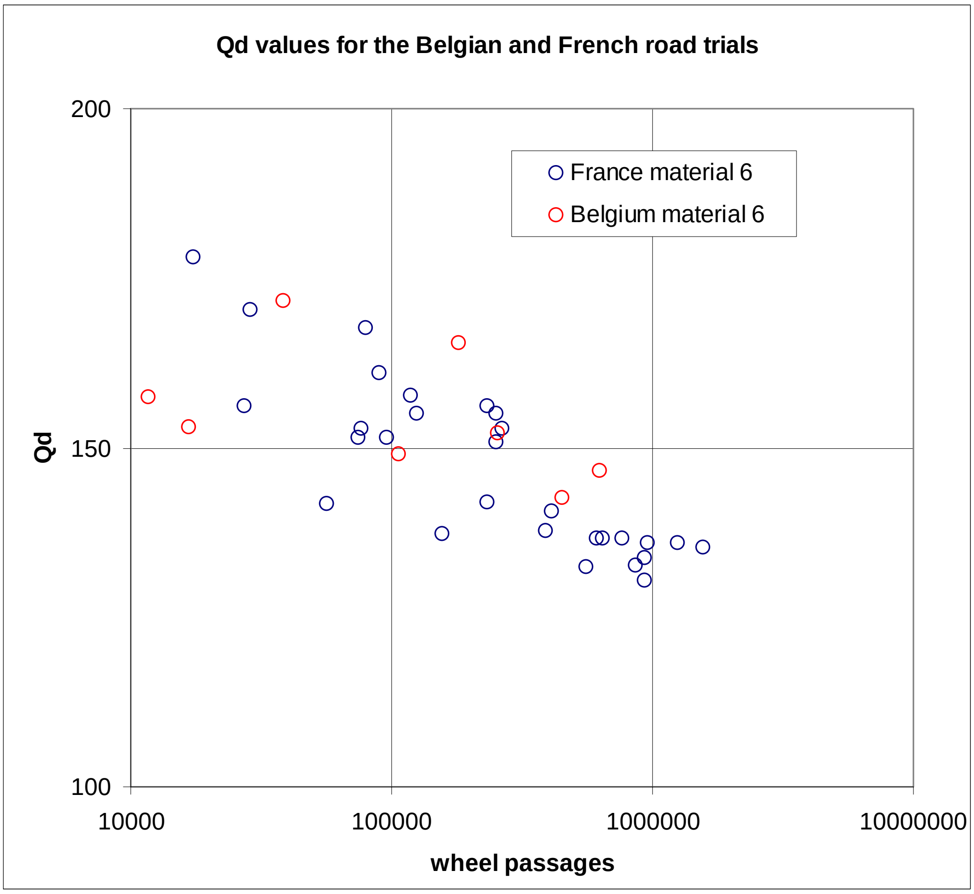


Figure 5.8: Qd values for the Belgian and French road trials versus wheel passages.

5.3.2 Load factors for R_L

Figure 5.9 shows a comparison of the load factor for R_L and the wheels passage number for the road trials of Belgium, Denmark, Finland, France and Sweden. The values are indicated by means of symbols, and trend lines are included in order to help interpretation of the diagram.

As the load for R_L is the logarithm of the load factor (refer to chapter 4), figure 5.9 uses a logarithmic axis for the load factor in order to provide the linear relationship mentioned in section 5.3.1. A trend line therefore reflects the assumption that the load factors increase exponentially with the number of wheel passages - meaning that R_L values decrease exponentially.

This load factor at zero wheel passages is larger for Finland and Sweden, and partly also for Denmark, than for Belgium and France. The reason may for instance be winter maintenance in the first-mentioned countries.

> EXAMPLE 1: The load factor for Finland in figure 5.9 is approximately 3,4 for zero wheel passages. This indicates an average reduction of the R_L values as compared to the initial or potential values by this factor.
>
> EXAMPLE 2: The trend line for Finland in figure 5.9 shows that the load factor increases from approximately 3,5 to approximately 7 - or a factor of 2 - after 200 000 wheel passages. With an exponential increase, the load factor increases by a factor of 4 after 400 000 wheel passages, a factor of 8 after 600 000 wheel passages etc.

The slope of the trend lines for Finland and Sweden, and partly also for Denmark, is higher than for Belgium and France. This has to be caused by the strong erosive action of studded tyres in the first-mentioned countries.

The trend lines for Finland and Sweden can in practice be considered to coincide. The same applies for the trend lines for Belgium and France. The trend line for Denmark is in between the two.

Figure 5.10 shows a similar diagram for the two wear simulators. The trend lines should be expected to be close, but are actually approximately a factor of 2 apart at low numbers of wheel passages. At the highest number of wheel passages of 4 000 000, the two trend lines approximately meet. Even at this number of wheel passages, the load factor is less than 3 - approximately 2,6 as an average for the two wear simulators.

Such a value is reached with much less wheel passages at the road trials - after approximately 600 000 wheel passages at the Belgian and French road trials, and after none or very few wheel passages at the other road trial sites.

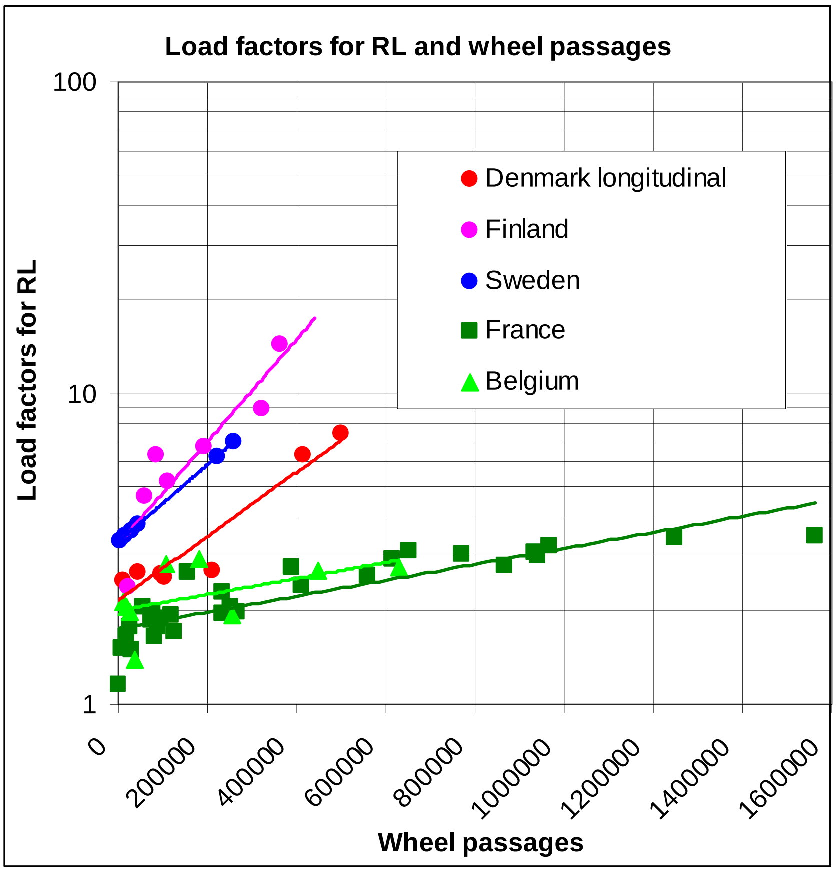


Figure 5.9: Wheel passages and load factors for R_L for road trials.

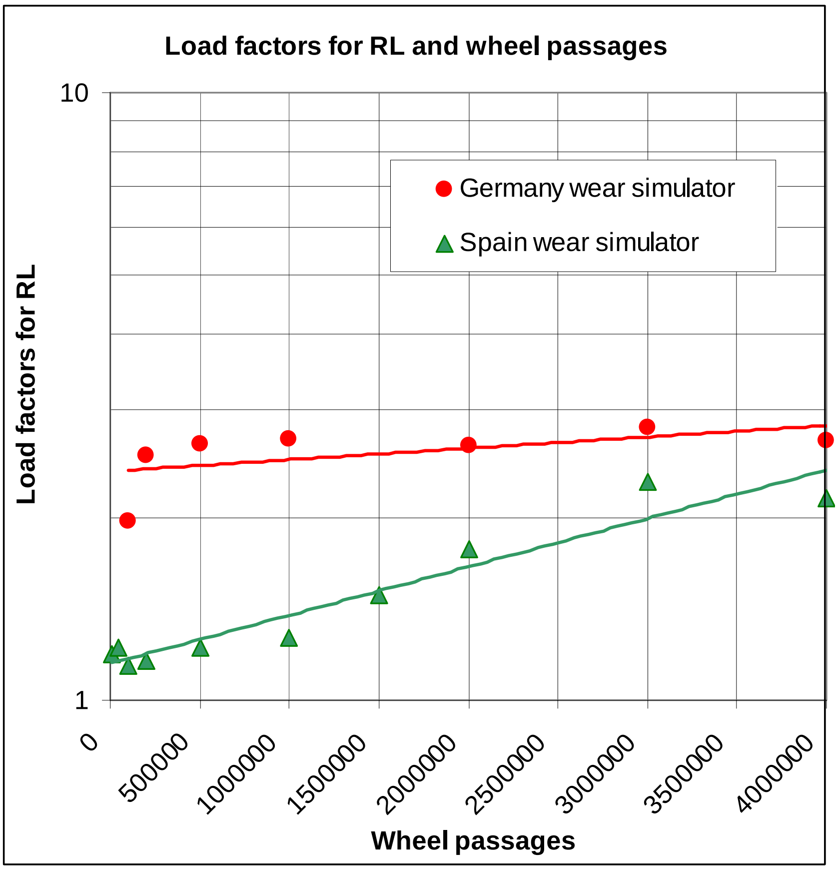


Figure 5.10: Wheel passages and load factors for R_L for wear simulators.

5.3.3 Loads for Qd and β

Figure 5.11 shows a diagram with a comparison of the loads for Qd and the wheels passage number for the road trials. Results for the transverse positions are indicated by symbols, and trend lines are included in order to help interpretation of the diagram.

The starting value of a trend line indicates a load at zero wheel passages that cannot be accounted for by wheel passages alone. The slope of a trend line reflects the assumption that the loads increase linearly with the number of wheel passages.

> EXAMPLE 1: The load for France in figure 5.11 is approximately 85 $cd \cdot m^{-2} \cdot lx^{-1}$ for zero wheel passages. This indicates such an average loss of the Qd values as compared to the initial or potential values.
>
> EXAMPLE 2: The trend line for France in figure 5.11 shows that the load increases from approximately 85 to approximately 100 - or 15 units - after 1 500 000 wheel passages. This corresponds to an average loss of Qd values of 1 $cd \cdot m^{-2} \cdot lx^{-1}$ per 100 000 wheel passages.

For Sweden and Finland, a strong increase of the load with the number of wheel passages would be expected due to erosion by studded tyres. However, Qd values were not measured for the Finnish road trial and the values for Sweden cannot be used to establish a trend line - probably because several measurements have been deleted due to strong erosion.

The slope of the trend line for Denmark is larger than for Belgium and France. The trend lines for Belgium and France can in practice be considered to coincide.

Figure 5.12 shows the diagram for the two wear simulators. The trend lines should be expected to be close, but after a start at approximately 25 $cd \cdot m^{-2} \cdot lx^{-1}$ at low numbers of wheel passages the lines actually separate to become almost 100 $cd \cdot m^{-2} \cdot lx^{-1}$ apart at the highest number of wheel passages.

The trend line for the German wear simulator shows a remarkable feature of decreasing from a low start value.

The loads for β are shown in the diagram of figures 5.13 and 5.14.

Concerning the road trials, the diagram in figure 5.13 is quite similar to the diagram in figure 5.11 - excepting of course that the units of the loads are those for respectively β and Qd.

The trend line for Finland does confirm the expected strong increase with the number of wheel passages. As for Qd, the β values for Sweden cannot be used to establish a trend line - probably because several measurements have been deleted due to strong erosion. Again as for Qd, the slope of the trend line for Denmark is larger than for Belgium and France. The trend lines for Belgium and France can in practice be considered to coincide.

As β was not measured for the German wear simulator, the diagram in figure 5.14 for the wear simulators show results for the Spanish wear simulator only. As for Qd, the load for β shows a slow increase with the number of wheel passages.

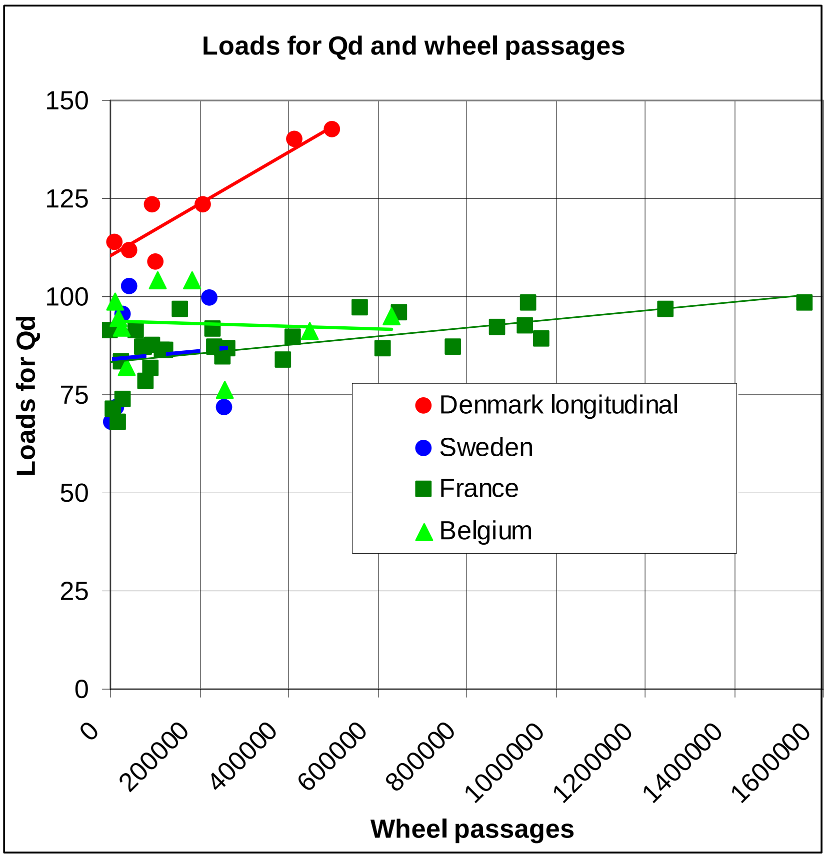


Figure 5.11: Wheel passages and loads for Qd for road trials.

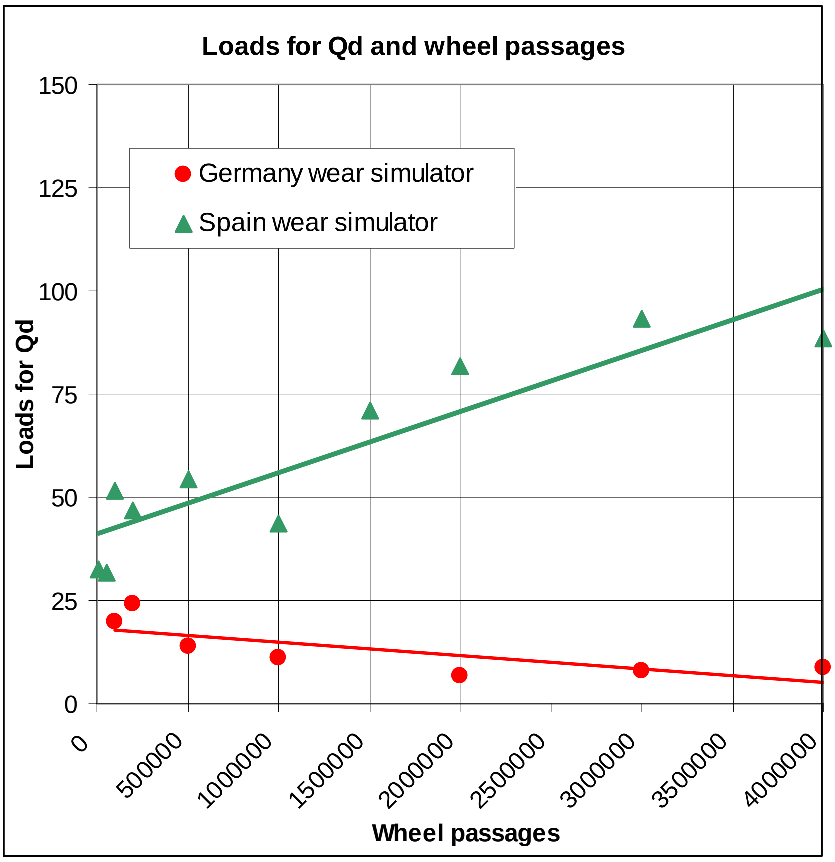


Figure 5.12: Wheel passages and loads for Qd for wear simulators.

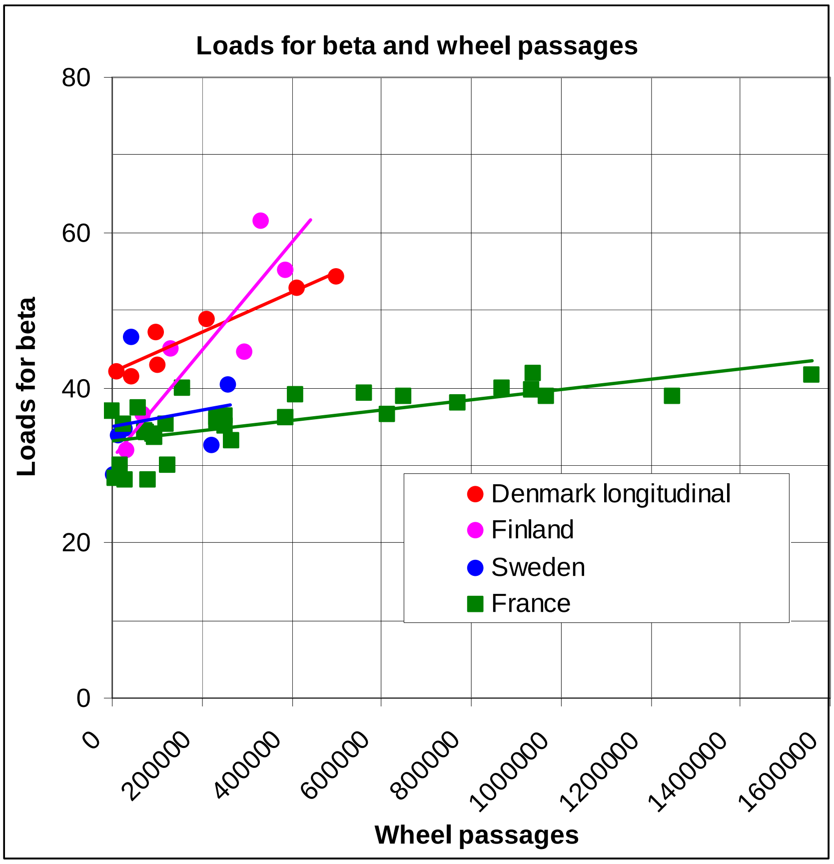


Figure 5.13: Wheel passages and loads for β for road trials.

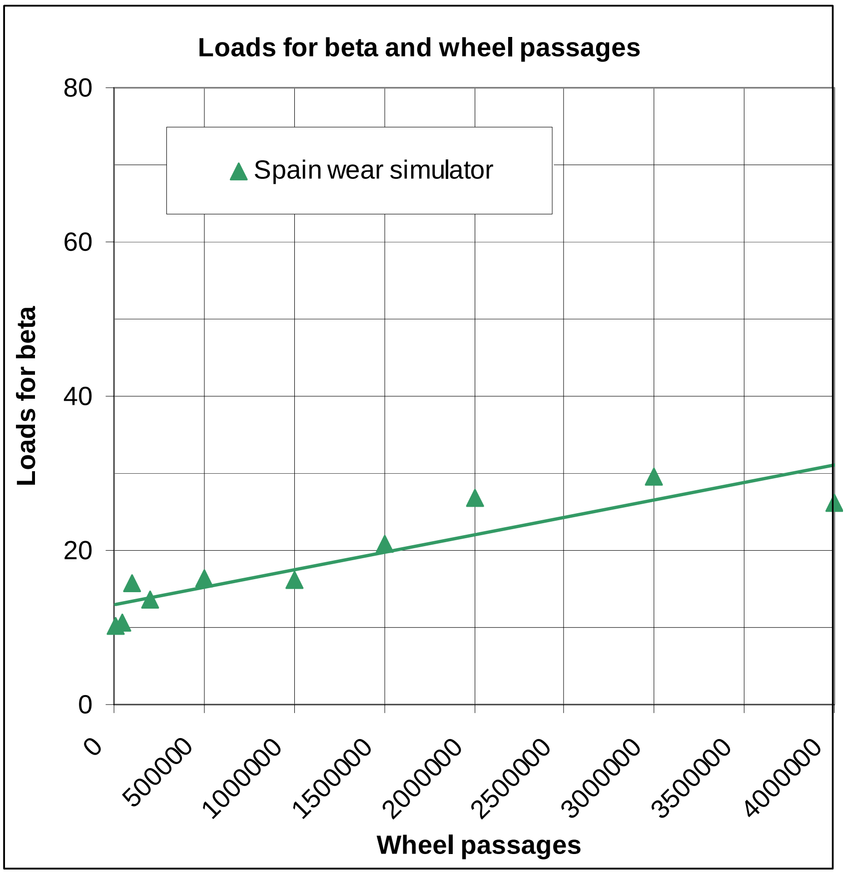


Figure 5.14: Wheel passages and loads for β for wear simulators.

5.4 Comparison of average loads and wheel passages

In order to provide some information for those road trial sites, where the wheel passage distribution has not been supplied, a simple comparison of loads and wheel passages is described in the following.

Figure 5.15 shows the average numbers of wheel passages for a number of test sites and also the average load factors for the R_L, the average loads for Qd and the average loads for β.

For those road trials, where the distribution of wheel passages is available, the average has been obtained as the simple average transverse to the road. For some other road trials, where the ADT is available, the average number of wheel passages has been estimated by comparison to the first-mentioned road trials. For the wear simulators, the average number of wheel passages has been found as the average of those numbers, where R_L values were measured (excluding the initial condition).

Figure 5.15 gives cause to the following observations:

- The Finnish and Swedish road trials - and partly the Danish road trials - have low average numbers of wheel passages, but the average loads are the highest.
- The Netherlands road trial has a high average number of wheel passages, but the average loads are medium or low.
- The remaining road trials in Austria, Belgium, the Czech republic, France and UK are intermediate to the above-mentioned road trials.
- The wear simulators have high average numbers of wheel passages, but low average loads.

These observations agree with those of section 5.3 to the extent that the different trial sites are included in the detailed comparisons carried out in section 5.3.

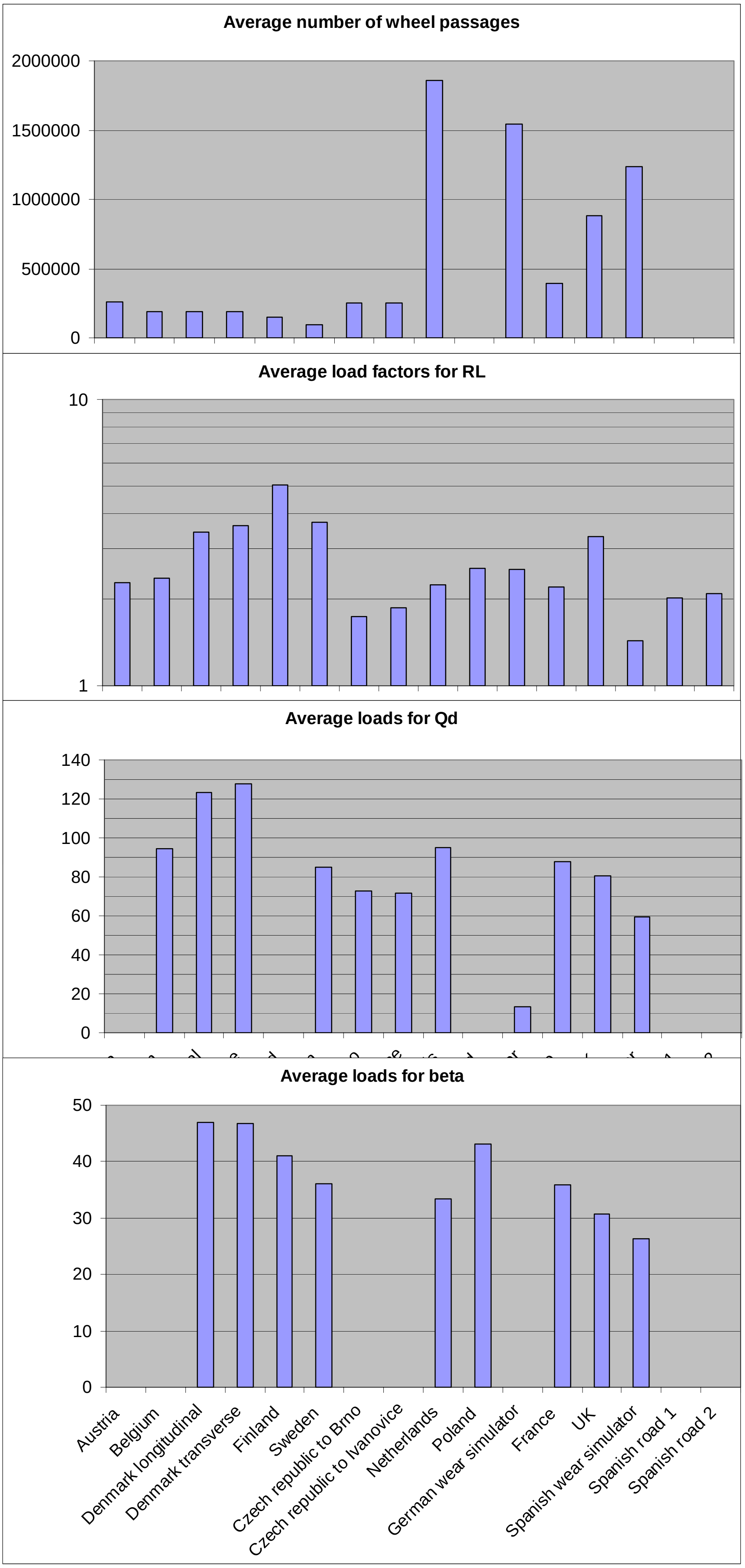


Figure 5.15: Average number of wheel passages and loads at the test sites.

Annex A: Models for the final data

A.1 Values representing a characteristics

A_{ijk} represents the values of a characteristic of the material i at the transverse location k at test site j. These values are the directly measured values, or the averages for longitudinal positions, whenever more than one measurement is done at different longitudinal positions.

> NOTE: In case of the characteristic R_L, A_{ijk} are logarithms of R_L values. Refer to annex B.

A.2 Approximation by models

The set of values formed by A_{ijk} is approximated by a set of values E_{ijk} obtained in a model description. The model assumes that a potential value can be achieved, but that a load leads to a depreciation at a rate determined by a sensitivity to the load:

$E_{ijk} = I_i - L_{jk}\times S_{ij}$
where I_i is a potential value
L_{jk} is a load
and S_{ij} is a sensitivity

A.3 Determination of the free parameters of a model

The free parameters of a model are determined in such a way that the sum of square deviations given by $SQ = \sum_{ijk}(A_{ijk} - E_{ijk})^2$ is minimum.

The value of L_{jk} that brings the sum of square deviations to a minimum is found by setting the derivative of the sum with regard to L_{jk} to zero, i.e.:

$$\delta\sum_{ijk}(A_{ijk} - E_{ijk})^2/\delta L_{jk} = \delta\sum_{ijk}(A_{ijk} - I_i - L_{jk}\times S_{ij})^2/\delta L_{jk} = -2\sum_i((A_{ijk} - I_i - L_{jk}\times S_{ij})\times S_{ij}) = 0$$

This leads to $L_{jk} = \sum_i((A_{ijk} - I_i)\times S_{ij})/\sum_i S_{ij}^2$.

In the same manner; the sum of square deviations is brought to a minimum by $S_{ij} = \sum_k((A_{ijk} - I_i)\times L_{jk})/\sum_i L_{jk}^2$ and $I_i = \sum_{jk}(A_{ijk} - L_{jk}\times S_{ij})$.

The values of I_i, L_{jk} and S_{ij} depend on each other in a linear fashion and can in principle be determined by solving a set of linear equation. This can be done in an iterative procedure:

a. assume some reasonable values of I_i, L_{jk} and S_{ij}
b. determine new L_{jk} values by means of the above-mentioned expression
c. determine new S_{ij} values by means of the above-mentioned expression
d. determine new I_i values by means of the above-mentioned expression
e. if the new values are not significantly different from the old values, stop the procedure, else go to step b

Terms in the above-mentioned sums that use values of A_{ijk} that are missing (either not measured or deleted according to some criterion) are omitted in the summations.

In practice step d was omitted, and I_i values were kept at pre-selected values intended to reflect reasonable initial or potential values.

The procedure was carried out by means of an Excel file, which computes new values of L_{jk} and S_{ij} and inserts the new values of L_{jk} automatically, while the operator replaces old S_{ij} values with new values (else a circular reference will occur). The sum of square deviations is recalculated in each step and also used for the decision to stop the procedure.

The results of the model calculations are the values of the load factors L_{jk}, the sensitivities S_{ij} and the sum of square deviations SQ.

A.3 Interpretation of a model

The product $L_{jk} \times S_{ij}$ represents the loss compared to the initial value I_i that occurred because of the load applied (abrasion by wheel passages and/or actions of climate). The scales of these factors are mutually dependent in the sense that one of the factors can be scaled up, if the other factor is scaled down in proportion. The scale of one of the factors has, therefore to be selected by some criterion. It has been chosen to represent the S_{ij} values in a scale, that brings the average for the materials to unity at each test site.

With this choice, an S_{ij} value represents the sensitivity of a material relative to the other materials (at a test site). An L_{jk} value can be assigned the unit of the initial value, and represents the loss compared to the initial value as an average for the different materials.

The distribution of S_{ij} values at a particular test site indicates partly the inherent sensitivities to the load of the materials (a thin material can be expected to be generally more sensitive to loads than a thicker material), but also particular features of a test site when compared to distributions at other test sites (a material may perform better at one test site than at other test sites). When two test sites have approximately the same distribution, a test at one test site can replace a test at the other test site in the sense that materials can be expected to be ranked in the same manner.

The level of L_{jk} values at a test site, on the other hand, represents the harshness of the test at that test site (for instance caused by the general level of traffic). The distribution reflects the variation of the load across the road (for instance caused by the variation of wheel passages across the road).

The sum SQ is to be evaluated in connection with the degrees of freedom of the model N, which is the number N_A of measured values A_{ijk}, from which is subtracted the number N_P of parameters used to fit the model values E_{ijk} to the measured values. This number is the sum of the numbers of L_{jk} and S_{ij} values.

The proportion SQ/N is an estimate of the variance σ^2 to which the model values fit the measured values; the square root is an estimate of the standard deviation σ.

A.4 Comparison of models

When two different models result in values SQ_1/N_1 and SQ_2/N_2, the ratio $(SQ_1/N_1)/(SQ_2/N_2)$ is a useful quantity in determining if one model gives a better representation than the other.

The starting point is the assumption that the two models are 'equally good' in the sense that the underlying variance values σ_1^2 and σ_2^2 are equal. If this assumption is true, then the ratio $(SQ_1/N_1)/(SQ_2/N_2)$ is a stochastic variable according to an F-distribution with the degrees of freedom N_1 and N_2.

If, however, the ratio exceeds a selected fractile of that F-distribution, for instance the 99% fractile, then the assumption can be rejected on a significance level corresponding to the selected fractile. This is the background for statements like 'model A is better than model B on a 99% significance level'.

Annex B: Models for R_L values

B.1 Use of the R_L values

The measured R_L values show large variation with the materials, the test sites and the transverse locations on the test sites. Model methods according to annex A should therefore be useful.

The initial or potential R_L values to be used in the models have been set to 300 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$. This value is applied for all materials except for material 6 (the tape) for which the value of 900 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ is used.

With such data, the main concern is normally to explain variations in terms of ratios of R_L values rather than in terms of differences of R_L values. Because of this, the model methods have been applied on $\ln(R_L)$ values instead on R_L values directly. The term $\ln(R_L)$ means the natural logarithm to the R_L value, which is the logarithm with the base e = 2,7183 to four decimal places.

> EXAMPLE 1: If R_L values as shown in the upper table are introduced into a model analyses directly, material B would dominate the results because of the large loss of R_L value. The $\ln(R_L)$ values shown in the lower table, on the other hand, would lead to equal emphasis on the two materials, as the losses are equal.

	Material A	Material B
R_L small load	100	1000
R_L large load	50	500
loss of R_L	50	500

	Material A	Material B
$\ln(R_L)$ small load	4,61	6,91
$\ln(R_L)$ large load	3,91	6,21
loss of $\ln(R_L)$	0,70	0,70

The use of logarithmic R_L values agrees with the understanding that measuring uncertainty, repeatability or reproducibility of experiments is expressed in ratios or percentages. This is the normal understanding for R_L values. The ratio is derived by applying the exponential function to $\ln(R_L)$ values.

> EXAMPLE 2: If the standard deviation of $\ln(R_L)$ values is 0,1; the R_L values are subject to a variation with a factor of $e^{0,1}$ = 1,105, which could be understood as 10,5%.

When R_L values are small, their uncertainty may be large - when expressed by percentage. This would give small R_L values a dominating influence on results, even when they are too small to be of real interest. To avoid this, R_L values below 40 $mcd{\cdot}m^{-2}{\cdot}lx^{-1}$ have been omitted from the analyses. Such R_L values are met on the road trials of Denmark, Finland and Sweden, and at the German wear simulator.

Because of applying the model methods on $\ln(R_L)$ values instead on R_L values directly, a resulting load value can be considered to the logarithm of a factor by which the R_L values are reduced. In diagrams showing loads for R_L, these are presented in terms of such factors.

EXAMPLE 3: A load value of for instance 1,1 at a particular location means that the R_L values of the materials at that location are on the average reduced by a factor of $e^{1,1} = 2{,}7183^{1.1} = 3{,}00$.

Another consequence is that a resulting sensitivity for a particular material can be considered to be the power to which the load factor is applied for that material.

EXAMPLE 4: A sensitivity of for instance 1,46 for a particular material at a location, where the load factor is 3,00, means that the R_L value for that material at that location is reduced by a factor of $3{,}00^{1,46} = 5{,}00$.

B.2 Constant or individual sensitivities of the materials

Figure B1 shows the correlation between measured R_L values and model R_L values, when the model is based on constant sensitivities of the materials - meaning that the materials have individual sensitivity values, but the same values for all test sites.

The correlation is rather poor, with a standard deviation corresponding to a factor of 1,384.

NOTE: Twice the standard deviation corresponds to a factor of $1{,}384^2 = 1{,}915$, meaning that 95% of model R_L values are within approximately twice the measured R_L values and approximately half the measured R_L values.

Figure B2, on the other hand, shows the correlation, when the materials are allowed to have individual sensitivities - meaning that the values can be different for the different test sites/wear simulators.

This correlation is much better, with a standard deviation corresponding to a factor of 1,181. The improvement is significant to an extremely high degree.

The assumption of constant sensitivities of the materials has, therefore, to be rejected and at least some individual variation between test sites has to be accepted..

B.3 More detailed comparison of the test sites

Figure B3 shows the distributions of sensitivity of the materials, as derived in a model comprising individual models for a group of five road trials, the Belgian, French, Polish, UK and Danish longitudinal. The distributions are similar, with some characteristic features like relatively high sensitivities for the paints.

Figure B4 shows a single distribution, as derived for a combined model for the group of trials together.

Both these models result in a standard deviation corresponding to a factor of 1,16, which means that the combined model can safely be accepted. The conclusion is that the road trials within the group rate the materials in the same way.

Figures B5 and B6 provide the same conclusion for the two road trials of the Czech republic, figures B7 and B8 for the road trials of Finland and Sweden and figures B9 and B10 for the two wear simulators. The standard deviations corresponds to factors of respectively 1,17; 1,23 and 1,26.

The main features of the groups are:

- Belgium, France, Poland, UK and Denmark longitudinal: relatively high sensitivities for materials 4 and 5 (paints)
- Czech republic: high sensitivity for materials 1 and 2 (thermoplastic North and central) and very low for material 4 (thin applied paint)
- Finland and Sweden: high sensitivity for materials 4, 5 and 6 (paints and tape)
- wear simulators: high sensitivity for materials 1, 2 and 3, decreasing in this order (thermoplastics North, Central and South)

Figures B11, B12, B13 and B14 show the distribution of sensitivities for trial sites that have not been suggested as members of groups. These are respectively the Danish transverse, Austrian, Netherlands and Spanish roads. The main characteristic features are:

- Denmark transverse: high sensitivity for material 4 (thin applied paint)
- Austria: materials 1, 2 and 3 (thermoplastics) are not included
- Netherlands: approximately the same sensitivity for all materials
- Spanish roads: approximately the same sensitivity for all materials, except material 4 and 5 (the paints)

The Danish transverse road trial has the main feature of a large sensitivity of material 4 (thin applied paint, but is otherwise strongly similar to first-mentioned group. This main feature depends on only two R_L values obtained from heavily eroded transverse markings. Because of the small number of the R_L values, this trial site could be adopted into the group without rejection by the model statistics. This could also be reasonable in view of the eroded state of the markings.

The Austrian road trial could undoubtedly also be accepted into the first-mentioned group, without rejection by the model statistics. However, because of the omission of the materials 1, 2 and 3 (the thermoplastics) at this road trial, it is difficult to justify if this should be done or not.

The Netherlands road trial, on the other hand, can hardly be accepted into the other groups.

The two Spanish roads have been joined into one diagram in figure B14. However, the sensitivities for materials 4 and 5 differ between the two roads. Road No. 2 shows features similar to the Netherlands road trial.

B. 4 Loads

Each test site can be ascribed an average load value, formed as averages for transverse locations for road trials, and as averages for the different numbers of wheel passages at wear simulators. These load values are logarithmic values, but can be transformed into factors by applying the exponential function.

Figure B15 shows these average load factors for the different test sites. The factors range from approximately 1,4 for the Spanish wear simulator up to approximately 5 for the Finnish road trial (R_L values are on the average 5/1,4 = 3,6 times lower at the Finnish road trial than at the Spanish wear simulator). This range illustrates the variation of the loads from test site to test site.

The load is far from constant at a test site. As an example, figure B16 shows the distribution of load factors across the French road trial. The values are between 1,2 and 3,5 with an average of 2,2.

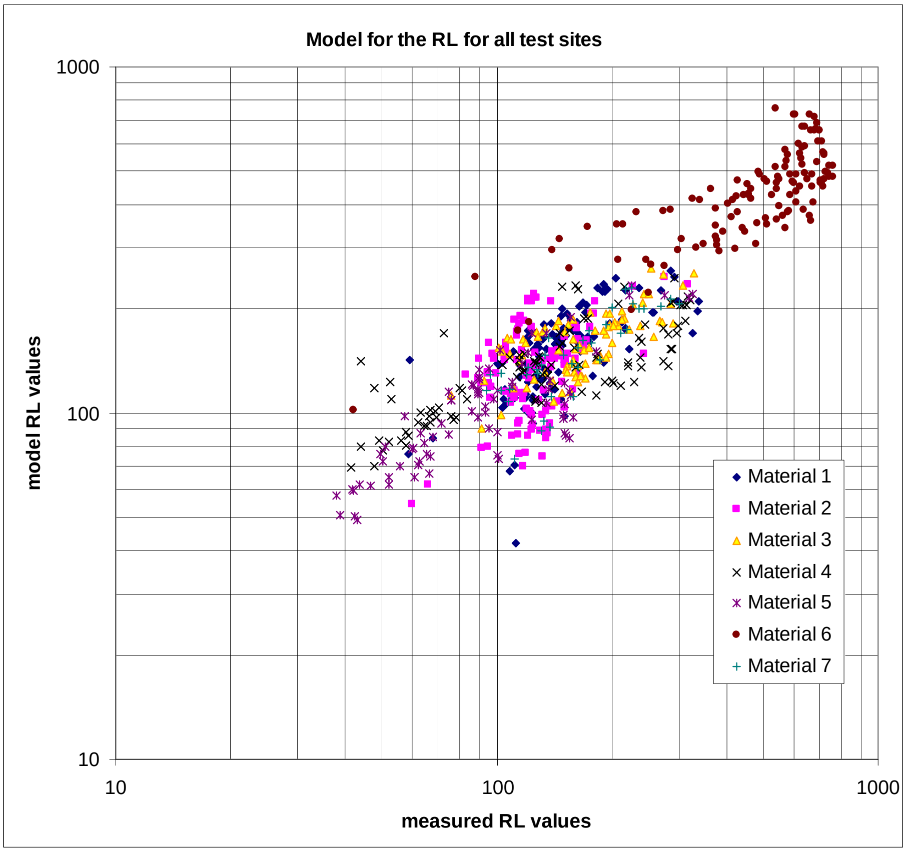


Figure B1: Correlation between measured R_L values and model R_L values based on constant sensitivities of the materials.

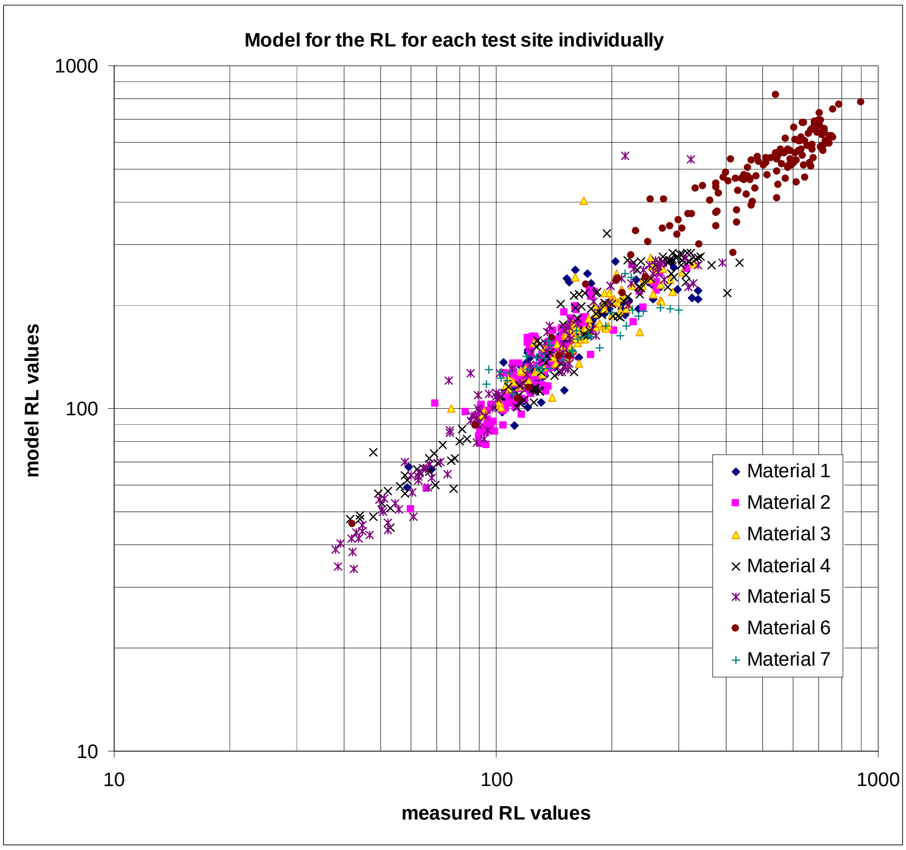


Figure B2: Correlation between measured R_L values and model R_L values based on individual sensitivities of the materials.

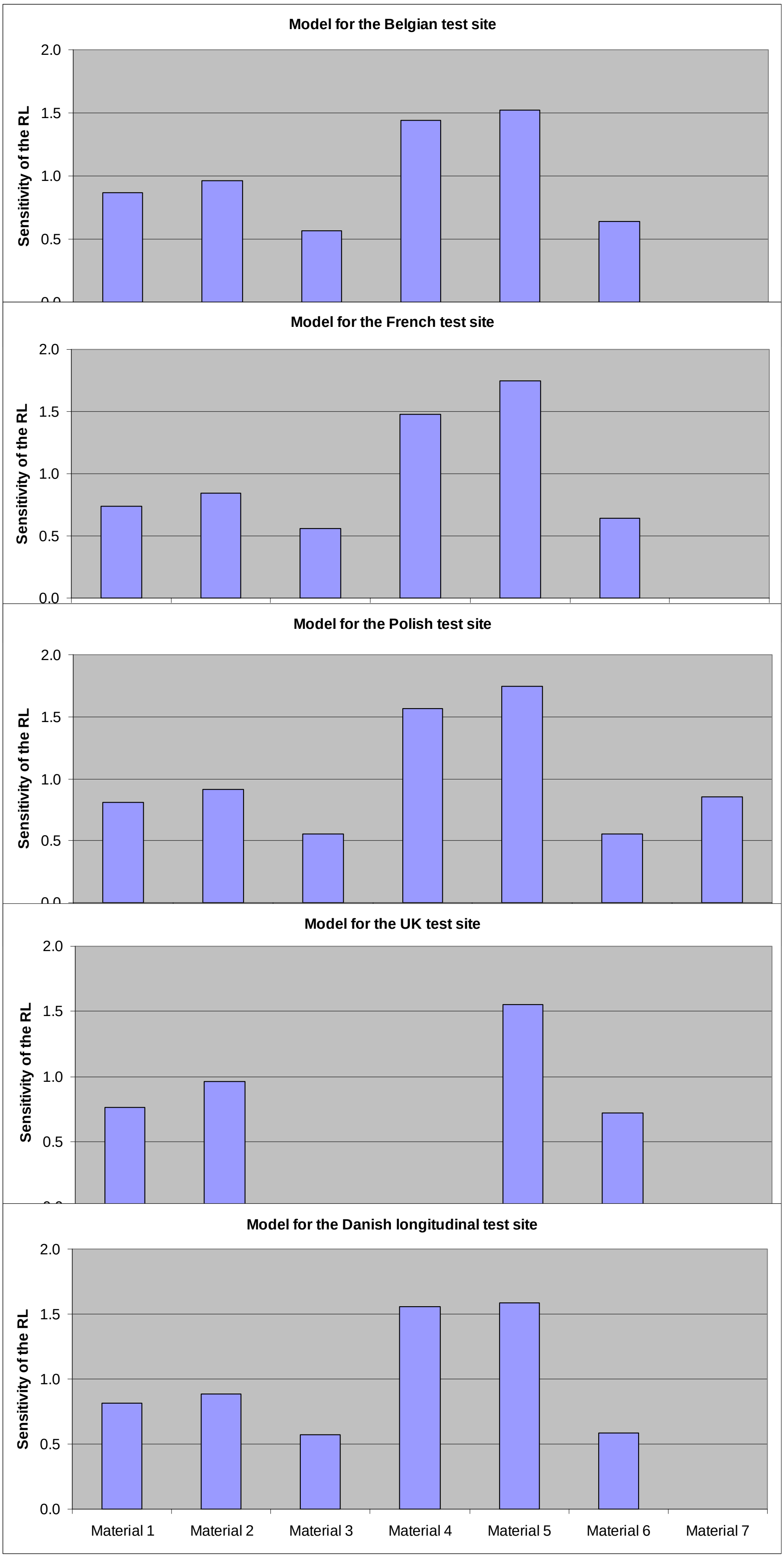


Figure B3: Sensitivity distributions for some road trials with similar distributions.

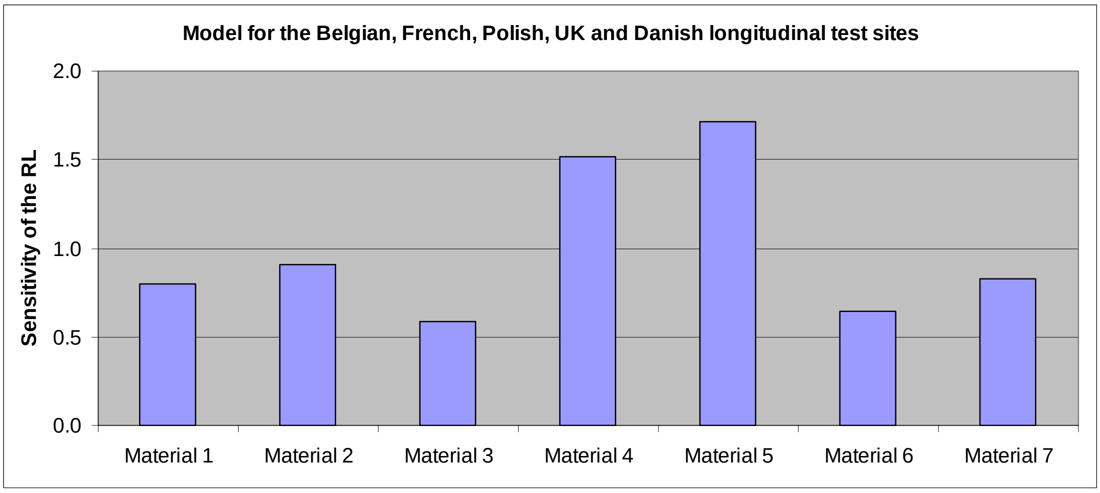


Figure B4: Single sensitivity distribution for some road trials.

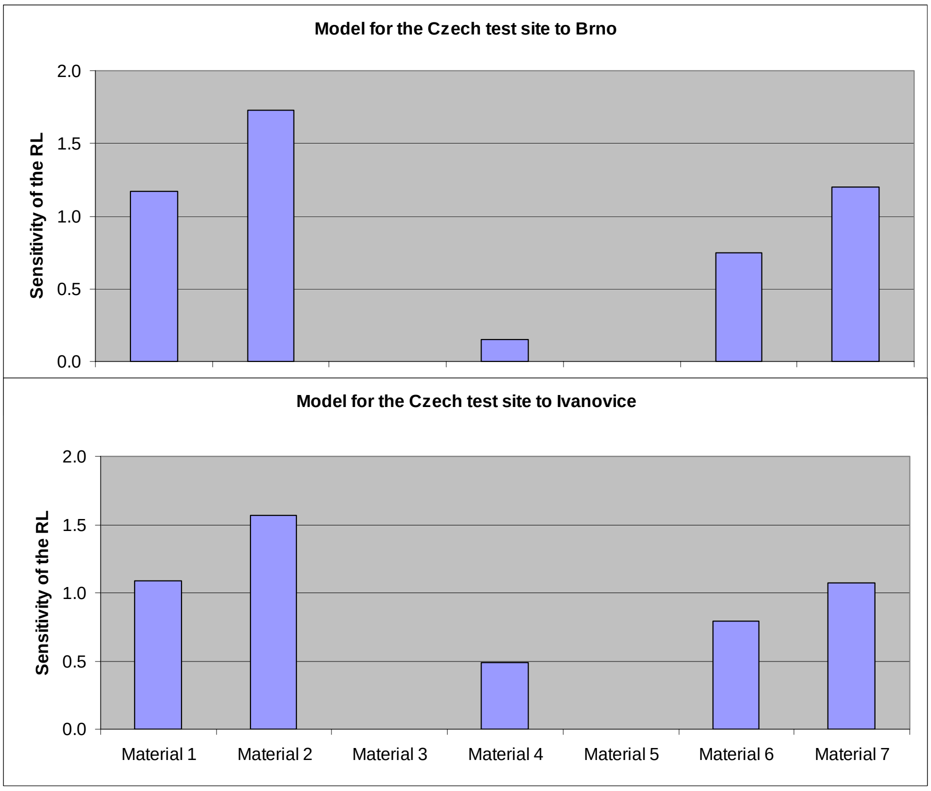


Figure B5: Sensitivity distributions for the two Czech road trials.

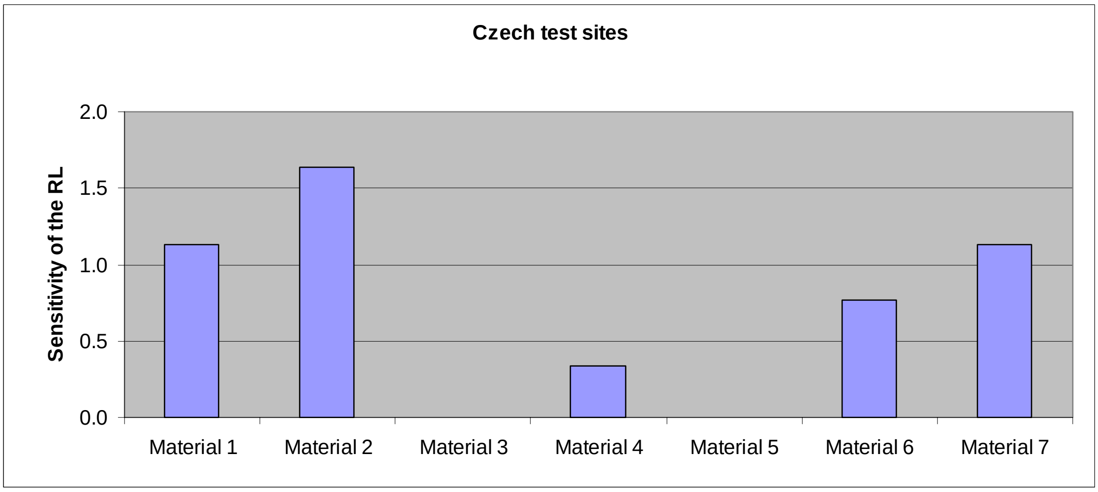


Figure B6: Single sensitivity distribution for the two Czech road trials.

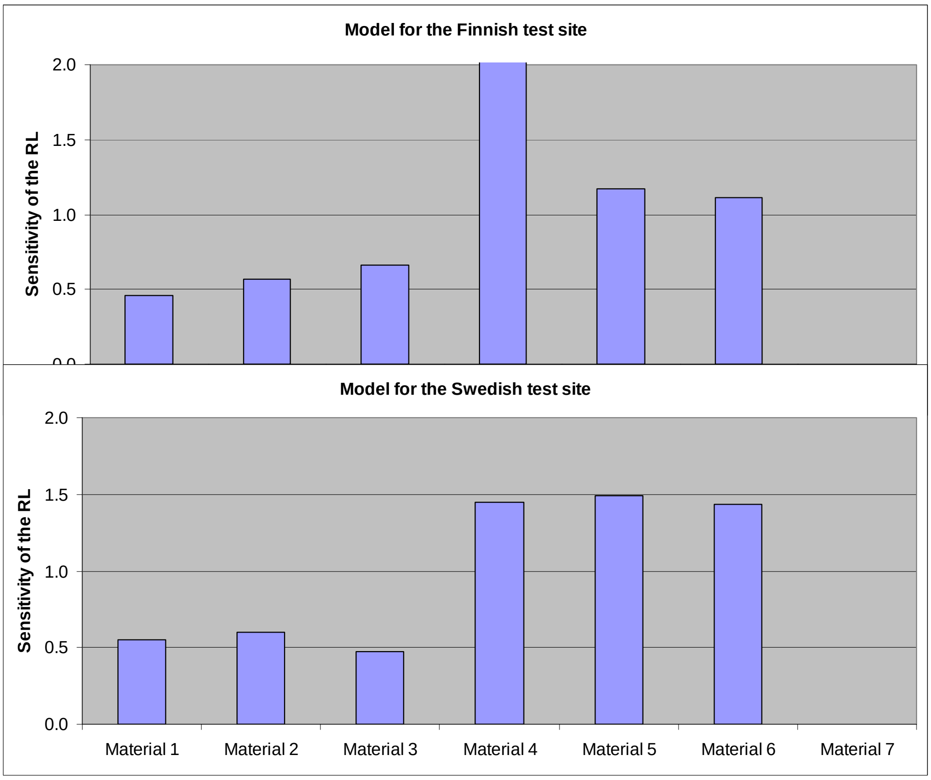


Figure B7: Sensitivity distributions for the Finnish and Swedish road trials.

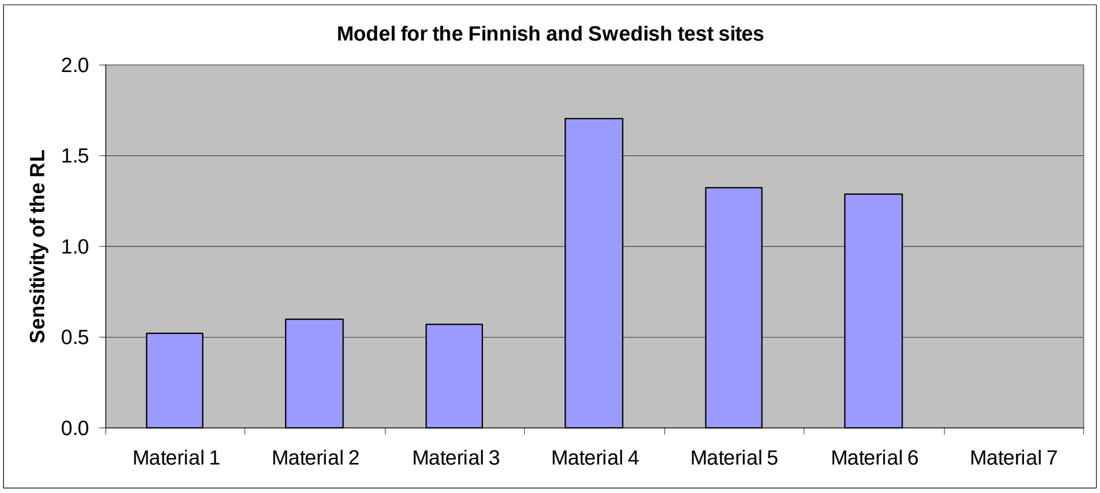


Figure B8: Single sensitivity distribution for the Finnish and Swedish road trials.

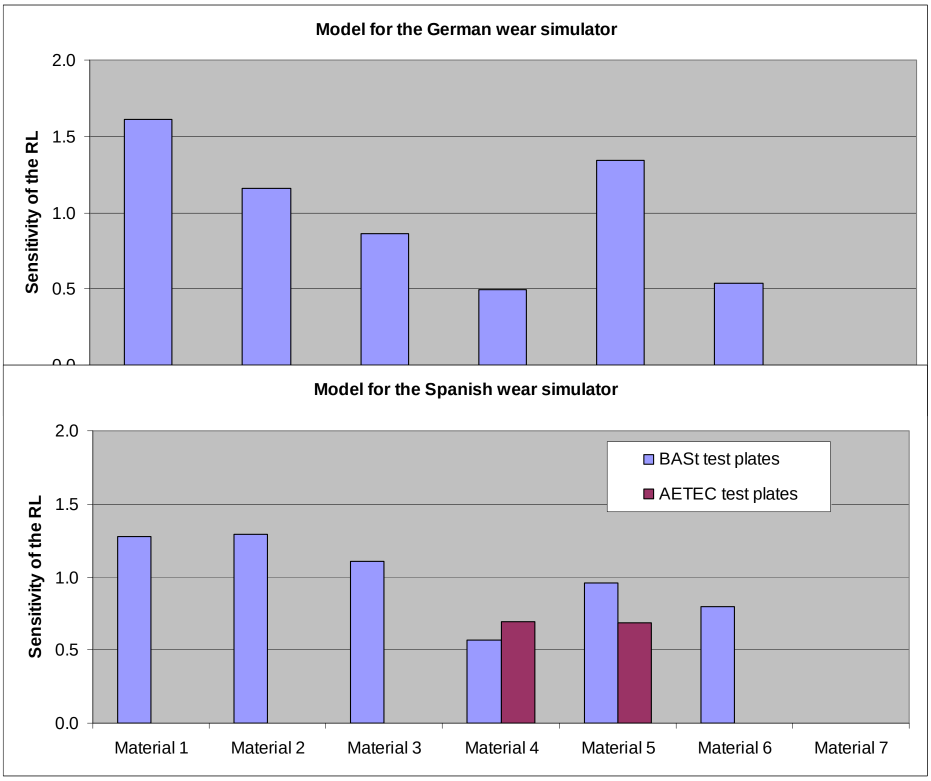


Figure B9: Sensitivity distributions for the wear simulators.

Figure B10: Single sensitivity distribution for the wear simulators.

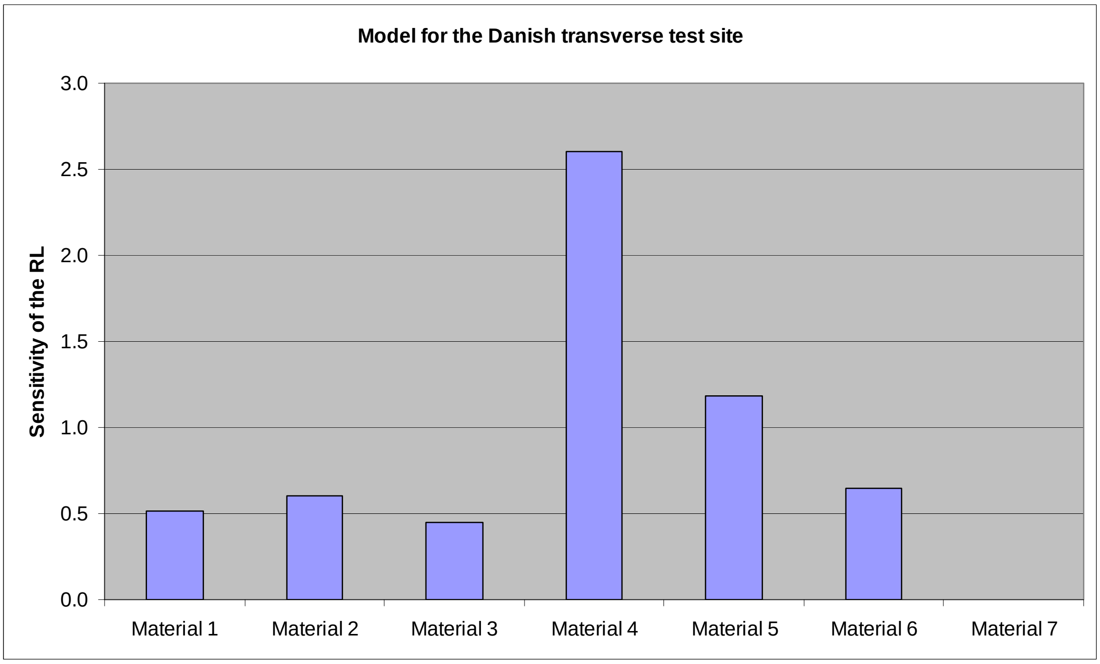


Figure B11: Sensitivity distribution for the Danish transverse road trial.

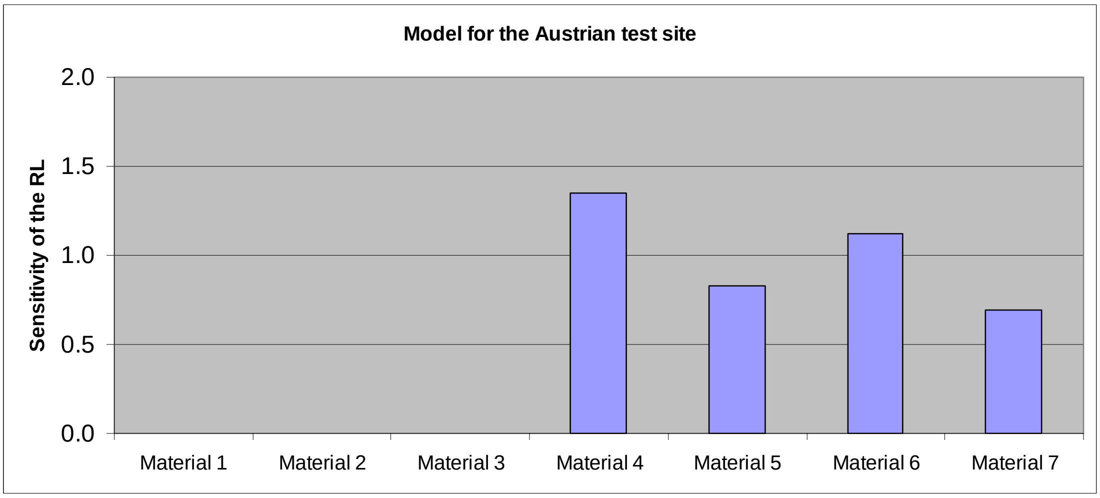


Figure B12: Sensitivity distribution for the Austrian road trial.

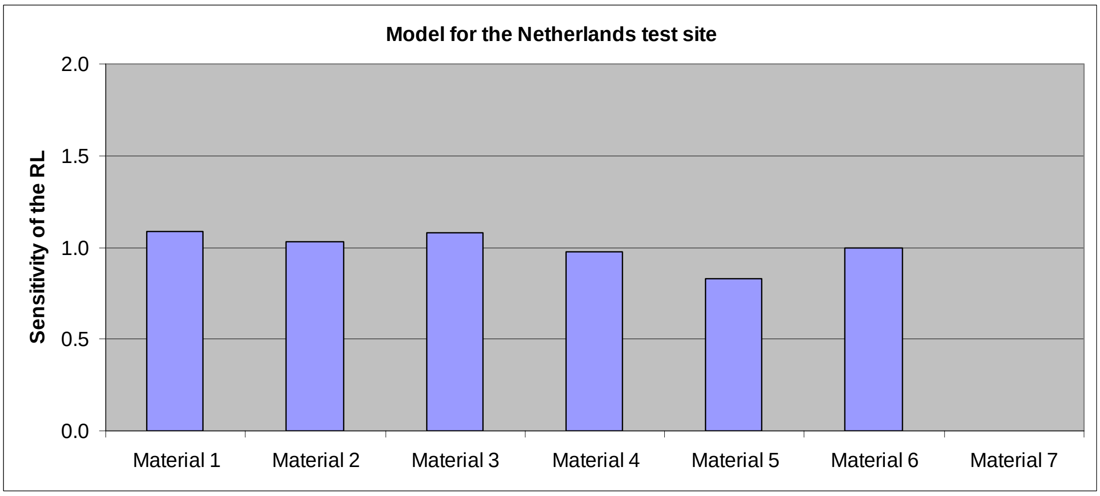


Figure B13: Sensitivity distribution for the Netherlands road trial.

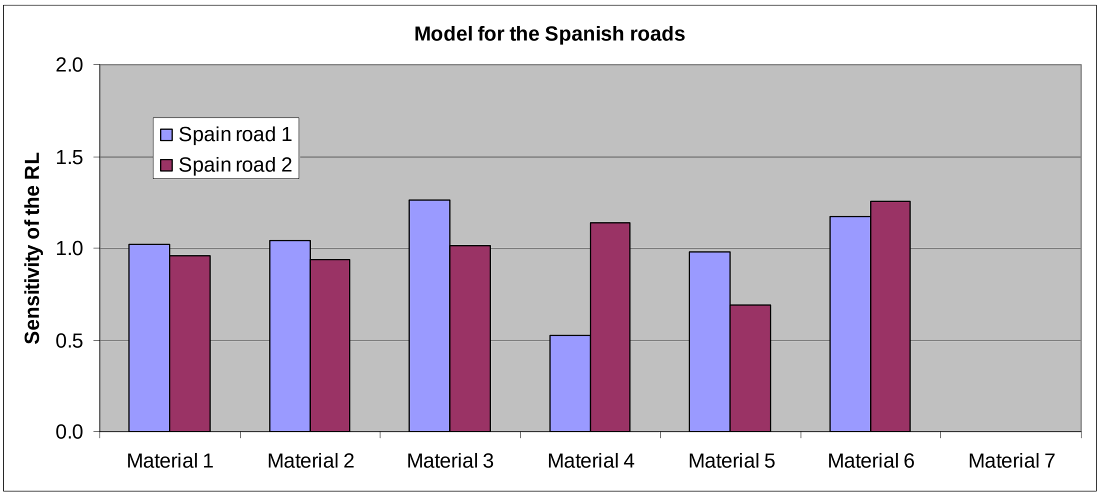


Figure B14: Sensitivity distributions for the Spanish roads.

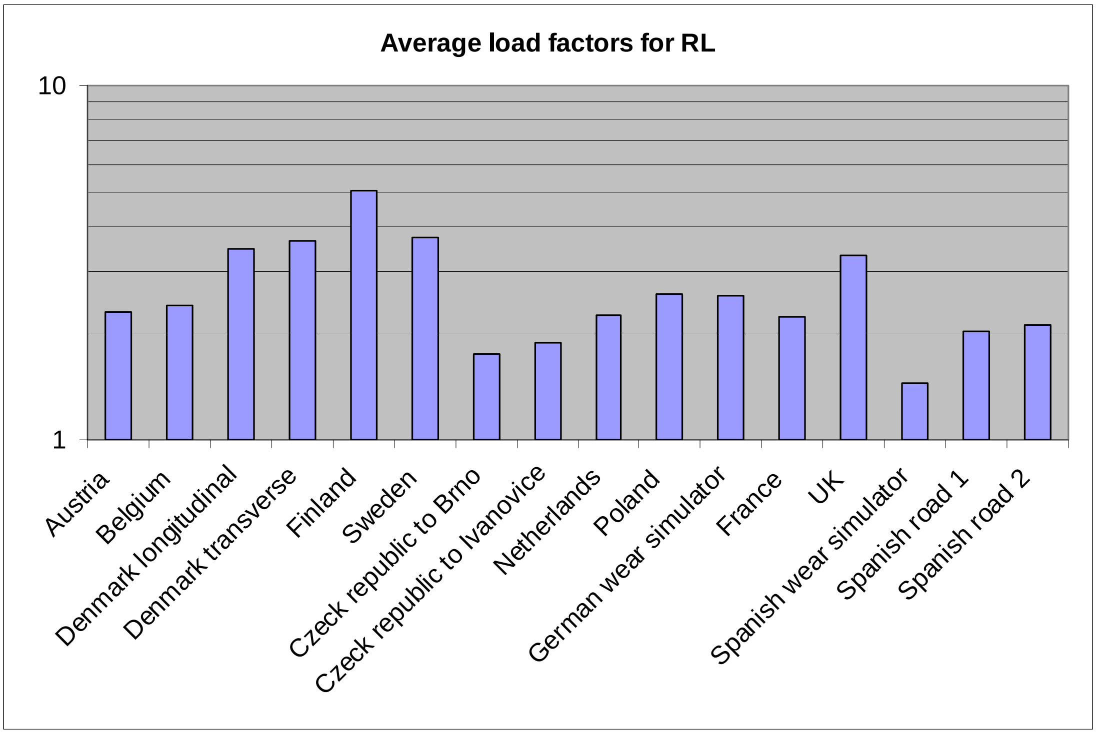


Figure B15: Average load factors for the R_L values.

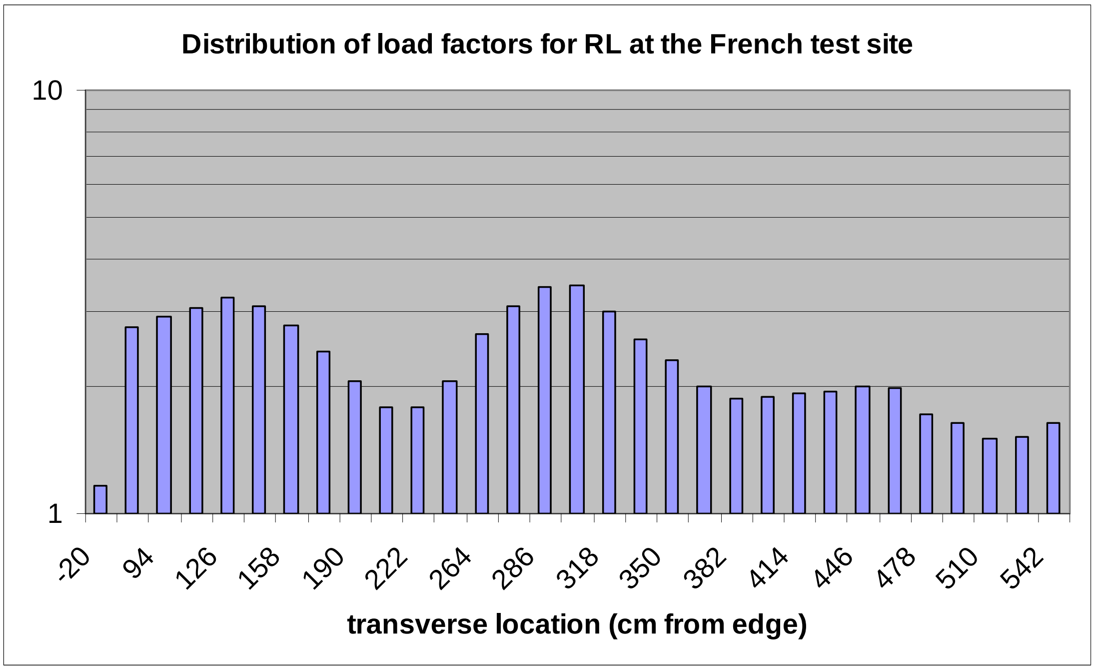


Figure B16: Variation of the load factor for the R_L values across the French road trial.

Annex C: Models for Qd values

C.1 Use of the Qd values

The measured Qd values show considerable variation with the materials, the test sites and the transverse locations on the test sites. Model methods according to annex A should therefore be useful.

The initial or potential Qd values to be used in the models have been set to 250 mcd·m^{-2}·lx^{-1} for all materials.

Qd values have mostly a limited variation within a factor of two. With such a variation, it is not crucial to decide if the model methods are to be applied on values directly or on logarithmic values. As the most simple, the Qd values have been used directly. This corresponds to the understanding that measuring uncertainty, repeatability or reproducibility of experiments is expressed directly in Qd units of mcd·m^{-2}·lx^{-1}.

Qd values in those positions, where R_L values were omitted from the analyses (refer to annex B) have also been omitted from the Qd analyses.

C.2 Constant or individual sensitivities of the materials

Figure C1 shows the correlation between measured Qd values and model Qd values, when the model is based on constant sensitivities of the materials - meaning that the materials have individual sensitivity values, but the same values for all test sites.

The correlation is rather poor, with a standard deviation of 19 mcd·m^{-2}·lx^{-1}.

> NOTE: Twice the standard deviation is 38 mcd·m^{-2}·lx^{-1}, which means that 95% of model Qd values are within ±38 mcd·m^{-2}·lx^{-1} of the measured Qd values.

Figure C2, on the other hand, shows the correlation, when the materials are allowed to have individual sensitivities - meaning that the values can be different for the different test sites/wear simulators.

This correlation is better, with a standard deviation of 12 mcd·m^{-2}·lx^{-1}. The improvement is significant to a very high degree.

The assumption of constant sensitivities of the materials has, therefore, to be rejected and at least some individual variation between test sites has to be accepted..

C.3 More detailed comparison of the test sites

Figure C3 shows the distributions of sensitivity of the materials, as derived in a model comprising individual models for a group of four road trial sites, the Belgian, French and UK. The group is the one considered in annex B, except that the Polish road trial site - where Qd was not measured - cannot be included. Additionally, the Danish longitudinal road trial has been excluded from the group, where it seems not to belong.

Figure C4 shows a single distribution, as derived for a combined model for the group of trial sites together.

The two models result in standard deviations of respectively 10,2 and 11,2 $mcd \cdot m^{-2} \cdot lx^{-1}$. This difference is not significant on a 95% level, and small in any case. This means that the combined model is acceptable.

Figure C5 shows the individual distributions for the two road trial sites of the Czech republic, and figure C6 the distribution for a combined model. The standard deviation is 5,0 $mcd \cdot m^{-2} \cdot lx^{-1}$ in both cases, which means that the combined model is acceptable.

The same test cannot be carried out for the Finnish and Swedish road trial sites, as the Qd was not measured at the Finnish road trial site. The distribution for the Swedish road trial site is shown in figure C7.

The distributions for the German and Spanish wear simulators are shown in figures C8 and C9 respectively. These test sites were made to form a group based on R_L values in annex B. However, the figures C8 and C9 show such large differences in sensitivity distributions, that a combined model for the two wear simulators would in this case provide a poor representation of either of the two sets of results. The distribution for the German wear simulator shows the feature of extremely low sensitivities for materials 4 and 5 (the paints).

The distributions for the Danish longitudinal and transverse road trials are shown in figures C10 and C11. These two deviate from each other in the sense that the distribution for the longitudinal road trial shows higher sensitivities for materials 1, 2 and 3 (the thermoplastics) than the distribution for the transverse road trial. This is due to dirt sticking to the longitudinal markings, which is unusual for Danish conditions. The transverse road trial, but not the longitudinal, could be included into the first-mentioned group of road trials.

The distribution for the Austrian road trial is shown in figure C12. The Austrian test site could undoubtedly also be accepted into other groups, without rejection by the model statistics. However, because of the omission of the materials 1, 2 and 3 (the thermoplastics) at this road trial, it is difficult to justify if this should be done or not.

The distribution for the Netherlands road trial is shown in figure C13. It shows low sensitivities for materials 1, 2 and 3 (the thermoplastics).

Qd has not been measured on the Austrian test site nor on the two Spanish roads.

C. 4 Loads

Figure C13 shows the average loads for the different test sites. The average loads represent the average reductions of Qd values compared to the initial or potential value of 250 $mcd \cdot m^{-2} \cdot lx^{-1}$; they range from 13 $mcd \cdot m^{-2} \cdot lx^{-1}$ for the German wear simulator up to more than 120 $mcd \cdot m^{-2} \cdot lx^{-1}$ for the Danish road trial sites.

As an example of variation of the load at a test site, figure C14 shows the distribution of loads across the French road trial site. The values are between 68 and 99 $mcd \cdot m^{-2} \cdot lx^{-1}$ with an average of 88 $mcd \cdot m^{-2} \cdot lx^{-1}$.

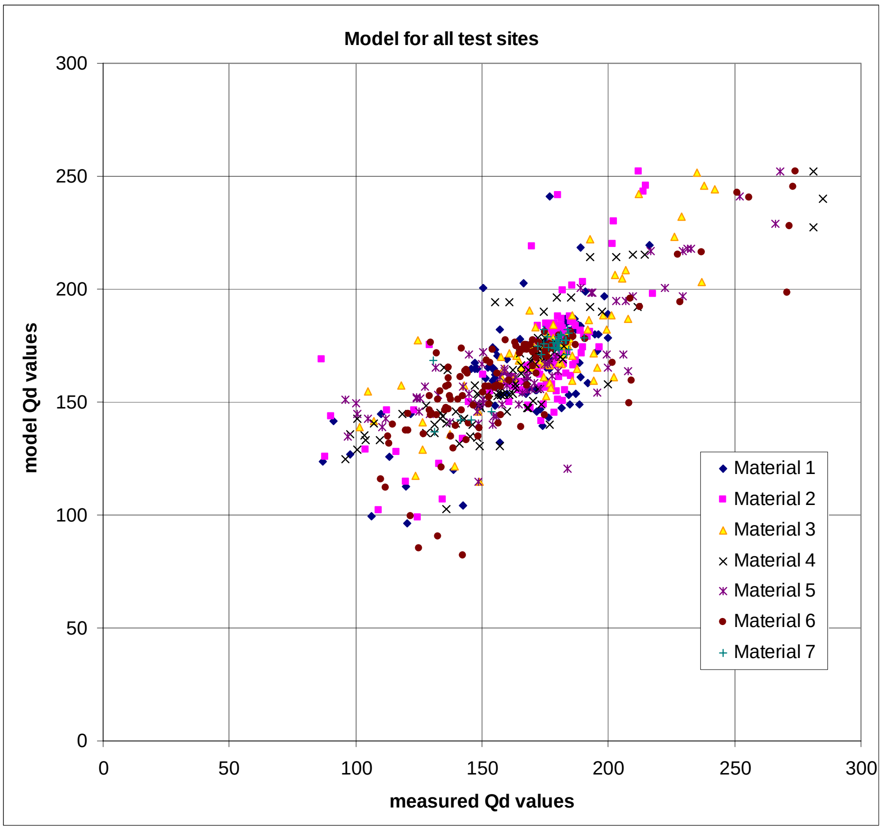


Figure C1: Correlation between measured Qd values and model Qd values based on constant sensitivities of the materials.

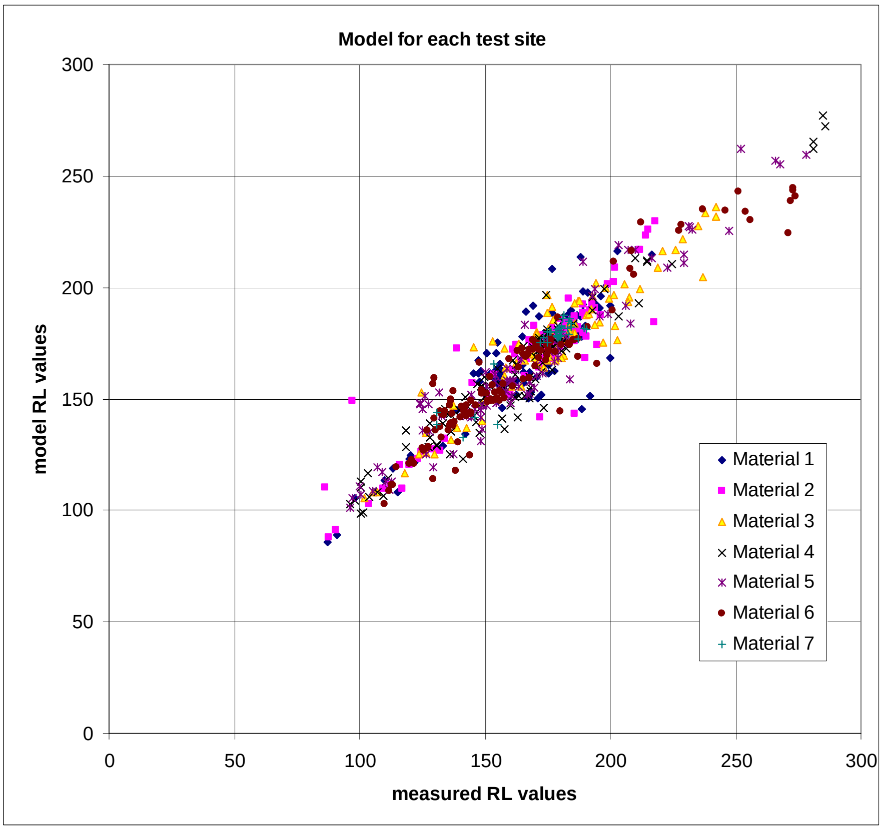


Figure C2: Correlation between measured Qd values and model Qd values based on individual sensitivities of the materials.

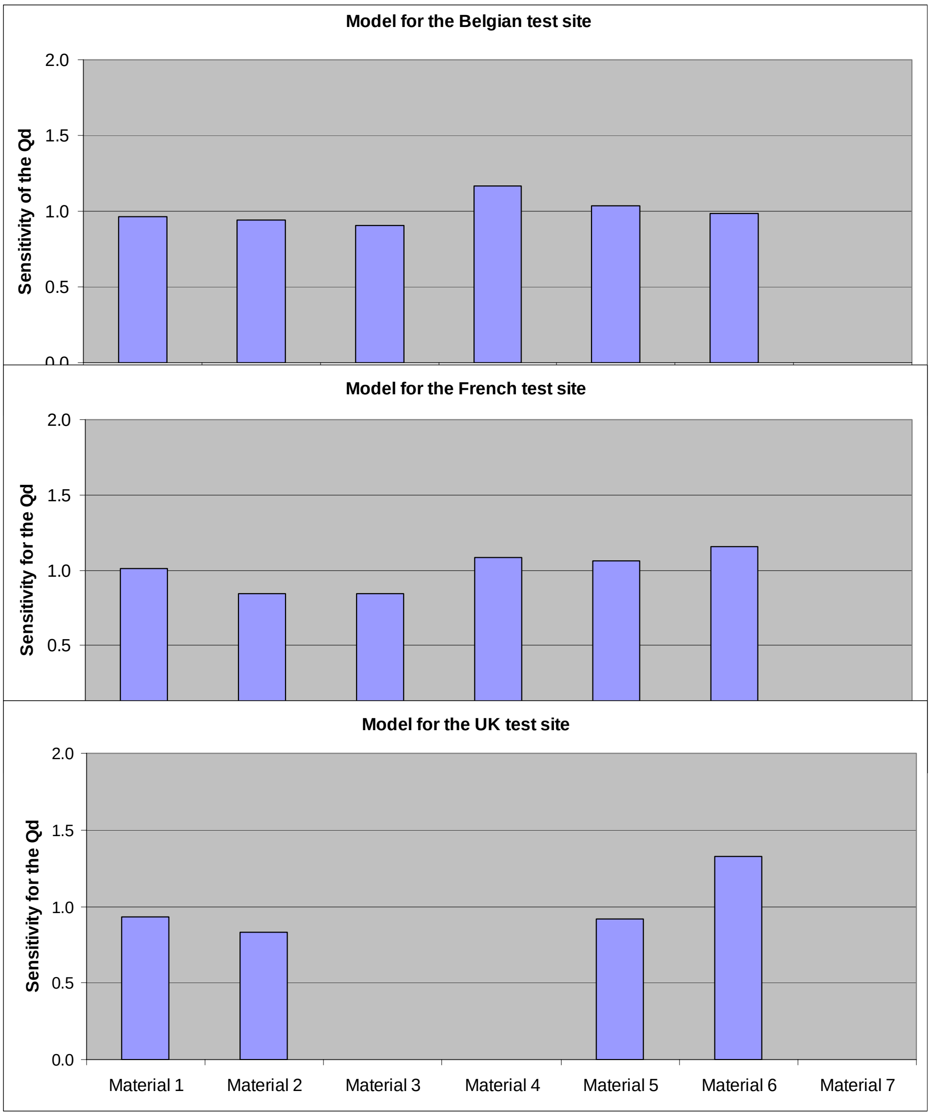


Figure C3: Sensitivity distributions for some road trials with similar distributions.

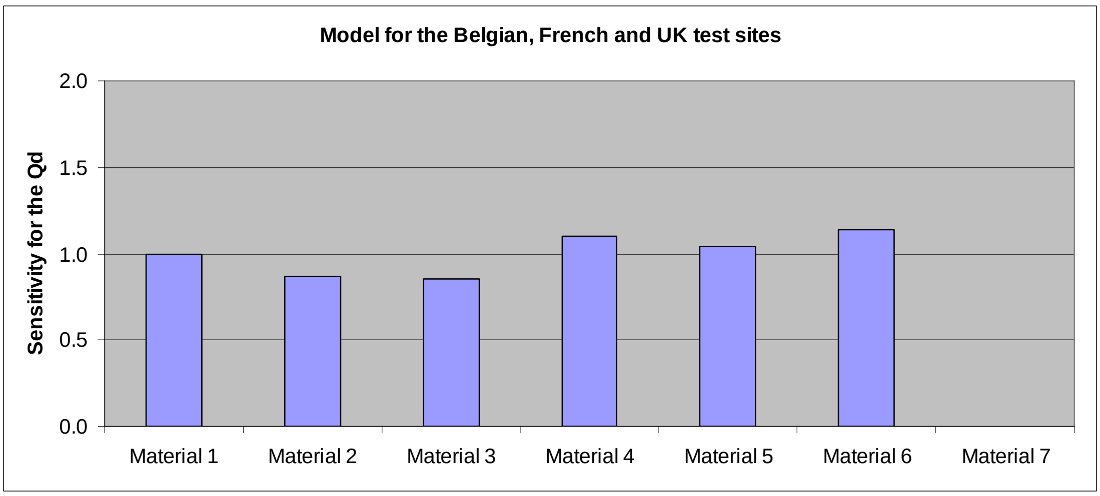


Figure C4: Single sensitivity distribution for some road trials.

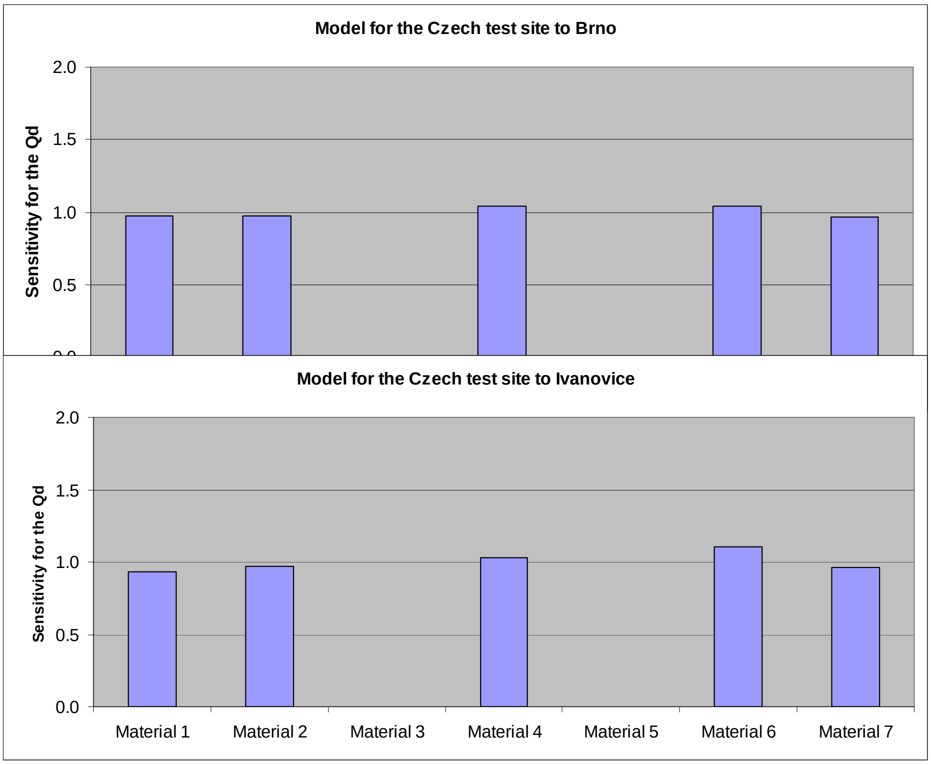


Figure C5: Sensitivity distributions for the two Check road trials.

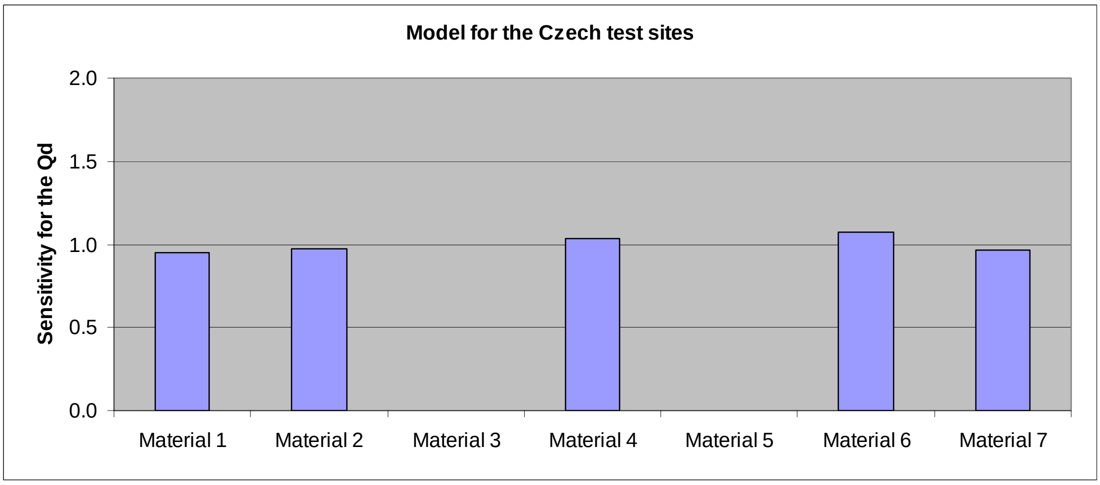


Figure C6: Single sensitivity distribution for the two Check road trials.

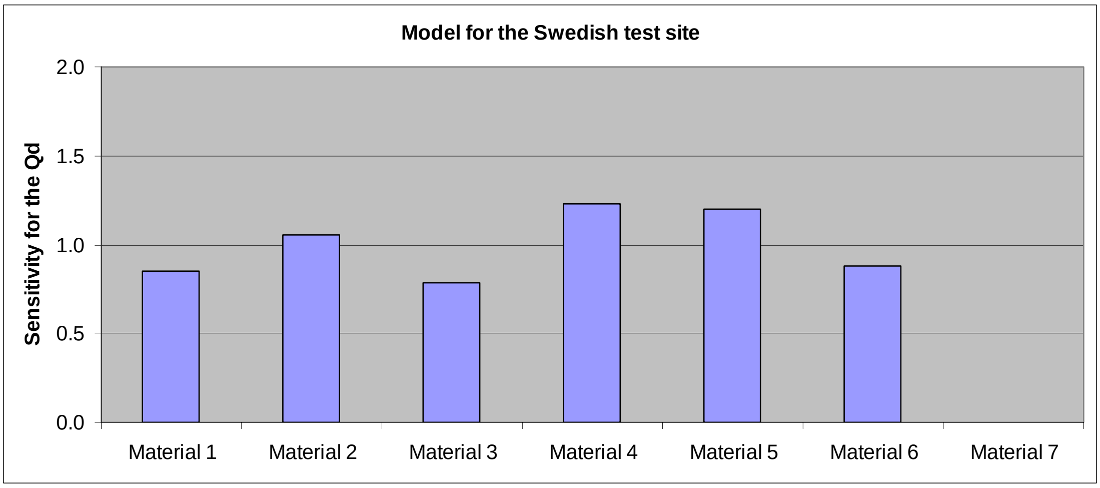


Figure C7: Sensitivity distribution for the Swedish road trial.

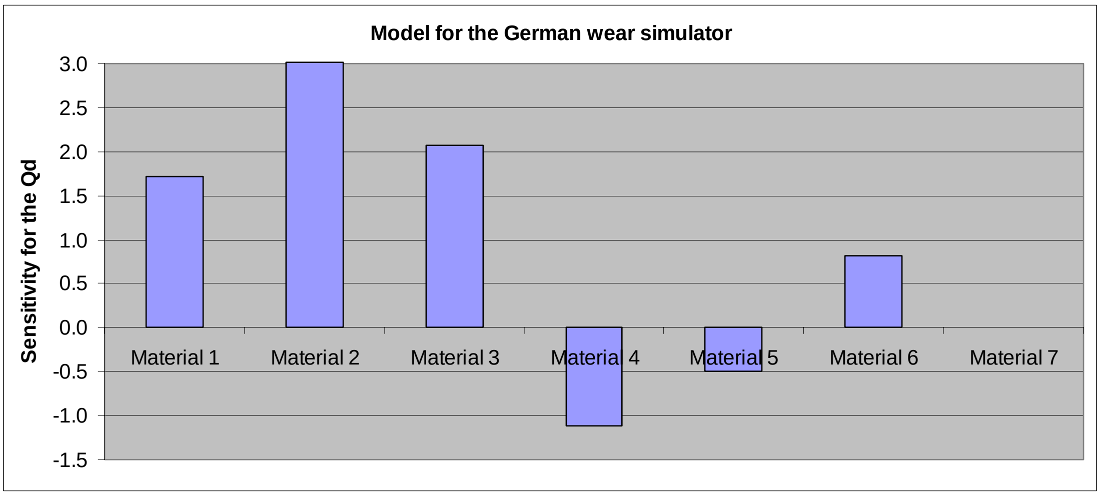


Figure C8: Sensitivity distribution for German wear simulator.

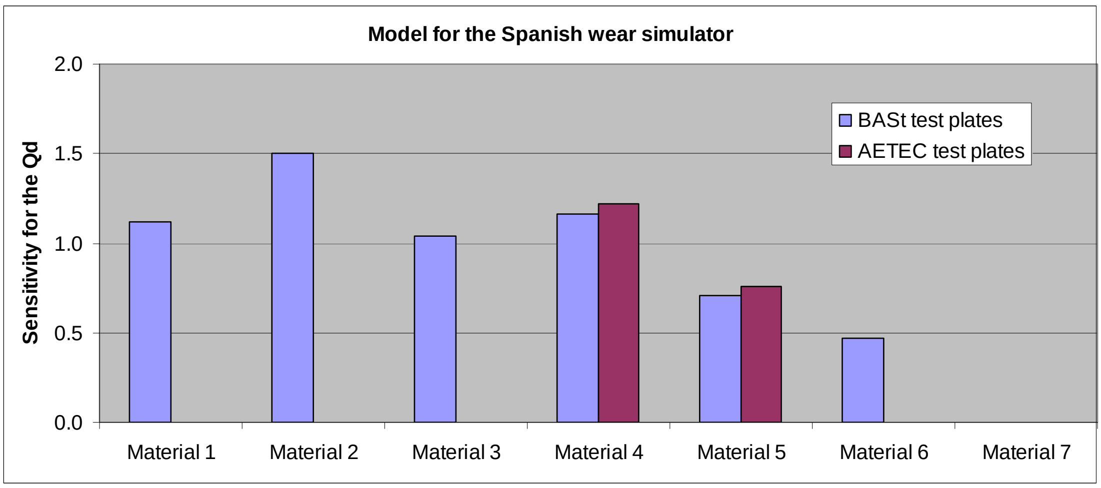


Figure C9: Sensitivity distribution for Spanish wear simulator.

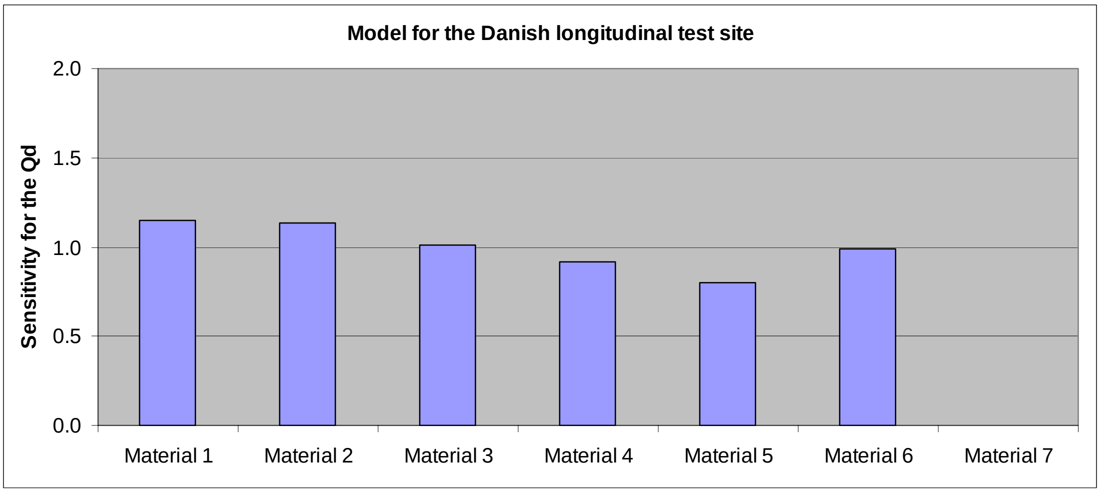


Figure C10: Sensitivity distribution for the Danish longitudinal road trial.

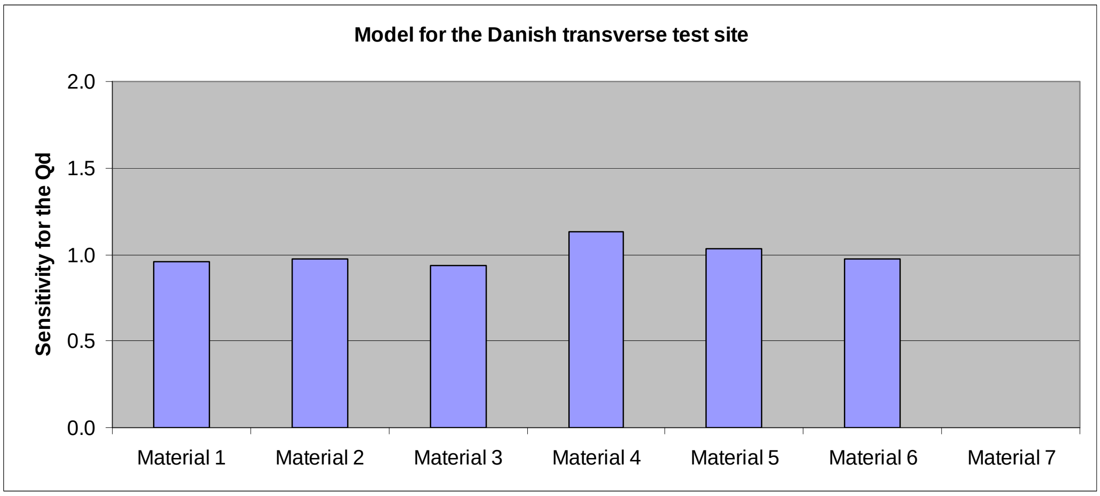


Figure C11: Sensitivity distribution for the Danish transverse road trial.

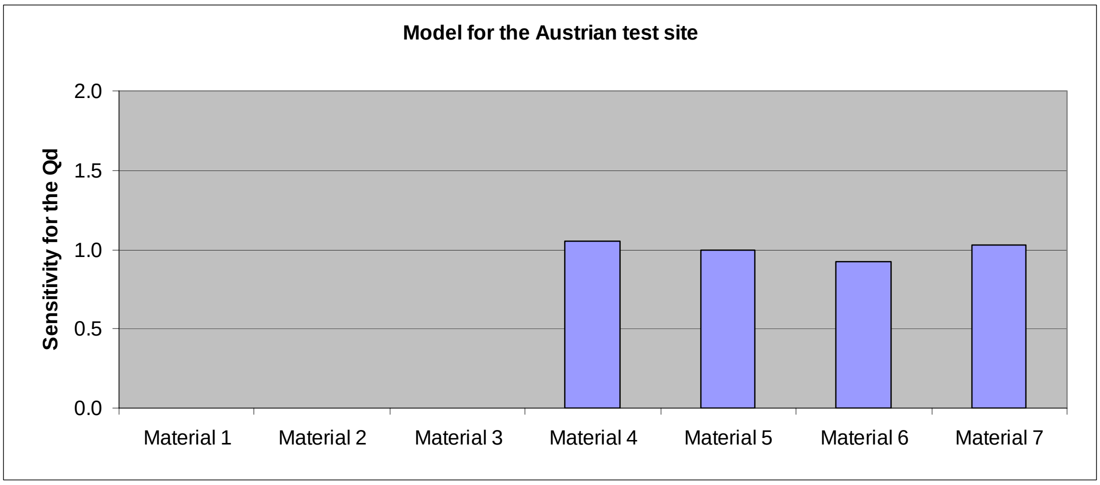


Figure C12: Sensitivity distribution for the Austrian road trial.

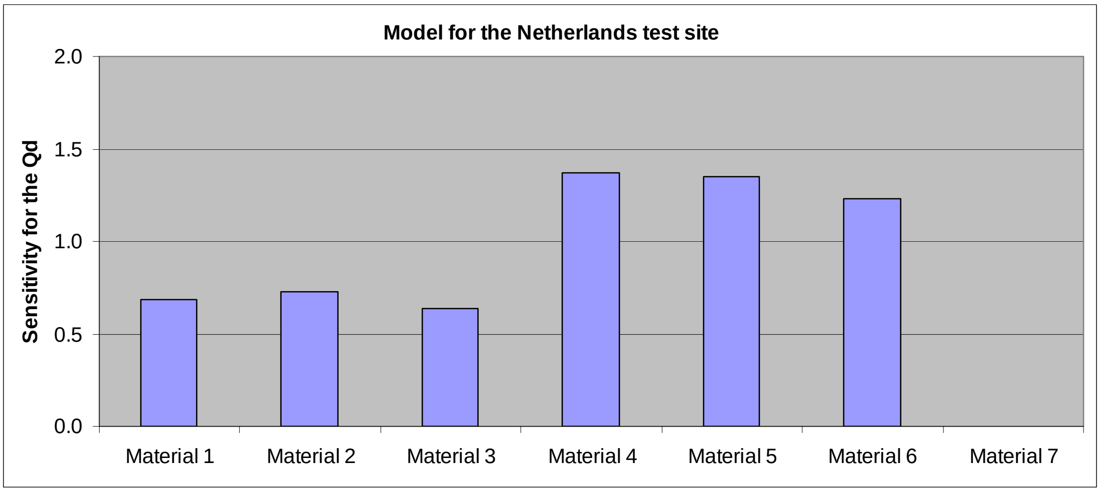


Figure C13: Sensitivity distribution for the Netherlands road trial.

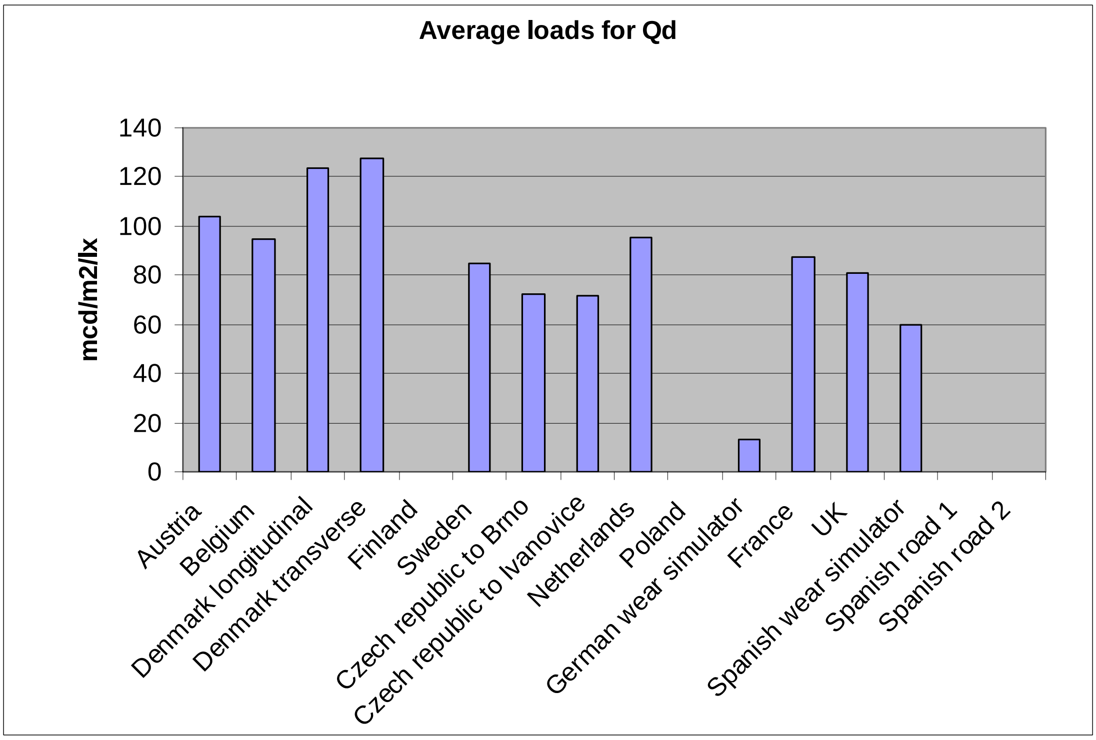


Figure C13: Average loads for the Qd values.

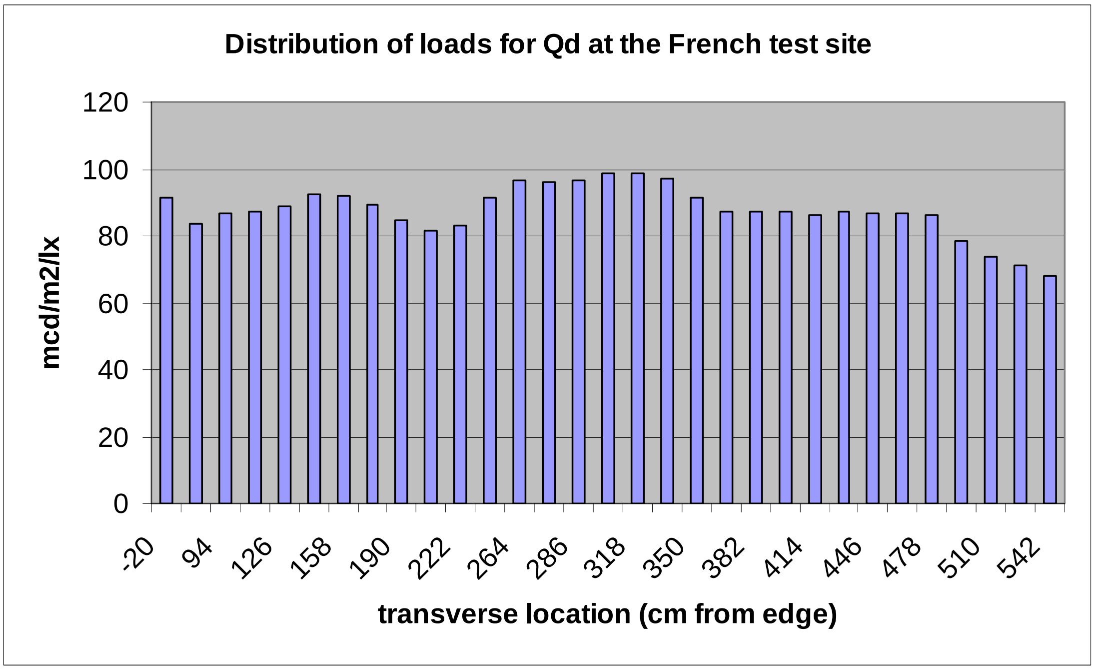


Figure C14: Variation of the loads for the Qd values across the French road trial.

Annex D: Models for β values

D.1 Use of the β values

The measured β values show considerable variation with the materials, the test sites and the transverse locations on the test sites. Model methods according to annex A should therefore be useful.

The β values are used on a scale from 0 to 100. The initial or potential β values to be used in the models have been set to 75 for all materials.

The β values have mostly a limited variation within a factor of two. With such a variation, it is not crucial to decide if the model methods are to be applied on values directly or on logarithmic values. As the most simple, the β values have been used directly. This corresponds to the understanding that measuring uncertainty, repeatability or reproducibility of experiments is expressed directly in β units.

The β values in those positions, where R_L values were omitted from the analyses (refer to annex B), have also been omitted from the β analyses.

D.2 Constant or individual sensitivities of the materials

Figure D1 shows the correlation between measured β values and model β values, when the model is based on constant sensitivities of the materials - meaning that the materials have individual sensitivity values, but the same values for all test sites.

The correlation is rather poor, with a standard deviation of 6,0.

> NOTE: Twice the standard deviation is 12, which means that 95% of model β values are within ±12 of the measured β values.

Figure D2, on the other hand, shows the correlation, when the materials are allowed to have individual sensitivities - meaning that the values can be different for the different test sites/wear simulators.

This correlation is better, with a standard deviation of 3,5. The improvement is significant to a very high degree.

The assumption of constant sensitivities of the materials has, therefore, to be rejected and at least some individual variation between test sites has to be accepted..

D.3 More detailed comparison of the test sites

Figure D3 shows the distributions of sensitivity of the materials, as derived in a model comprising individual models for the French, Polish and UK road trials. The group is the one considered in annex B, except that the Belgian road trial site cannot be included because β was not measured. Additionally, the Danish longitudinal road trial has been excluded from the group, where it seems not to belong.

Figure D4 shows a single distribution, as derived for a combined model for the French, Polish and UK road trials together.

The two models result in standard deviations of respectively 2,2 and 2,7. This difference is just barely significant on a 95% level. However, the difference is small, and the raise is to a low level, so the combined model is acceptable in practice.

The β values were not measured on the Czech road trial sites, which can therefore not be considered in terms of this characteristic.

The individual distributions for the Finnish and Swedish road trial sites are shown in figure D5, and the distribution for a combined model is shown in figure D6. The two models result in standard deviations of respectively 4,5 and 6,1. This difference is not significant on a 95% level, and small in any case. This means that the combined model is acceptable.

The β values were not measured at the German wear simulator and therefore the two wear simulators cannot be compared. The distribution for the Spanish wear simulator is shown in figure D7.

The distributions for the Danish longitudinal and transverse road trials are shown in figures D8 and D9. These two deviate from each other in the sense that the distribution for the longitudinal road trial shows higher sensitivities for materials 1, 2 and 3 (the thermoplastics) than the distribution for the transverse road trial. This is due to dirt sticking to the longitudinal markings, which is unusual for Danish conditions. The transverse road trial, but not the longitudinal, could be included into the first-mentioned group of road trials.

The β values were not measured on the Austrian and Netherlands road trial sites, nor on the two Spanish roads.

D.4 Loads

Figure D10 shows the average loads for the different test sites. The average loads represent the average reductions of β values compared to the initial or potential value of 75; they range from 26 for the Spanish wear simulator up to more than 45 for the Danish road trial sites.

As an example of variation of the load at a test site, figure D11 shows the distribution of loads across the French road trial site. The values are between 28 and 42 with an average of 36.

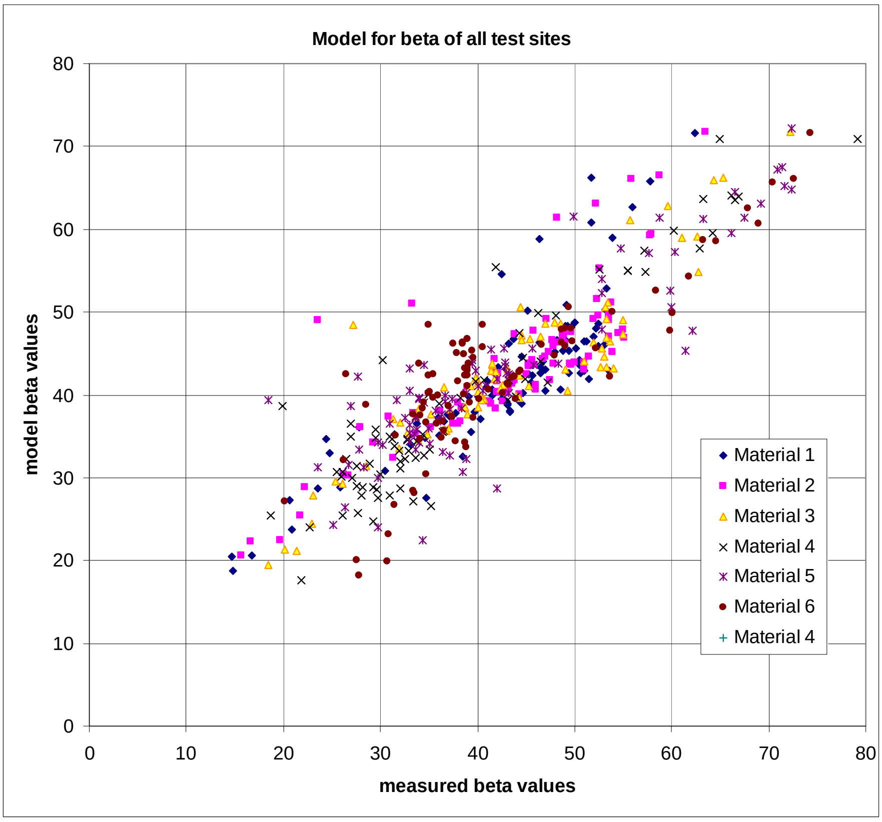


Figure D1: Correlation between measured β values and model β values based on constant sensitivities of the materials.

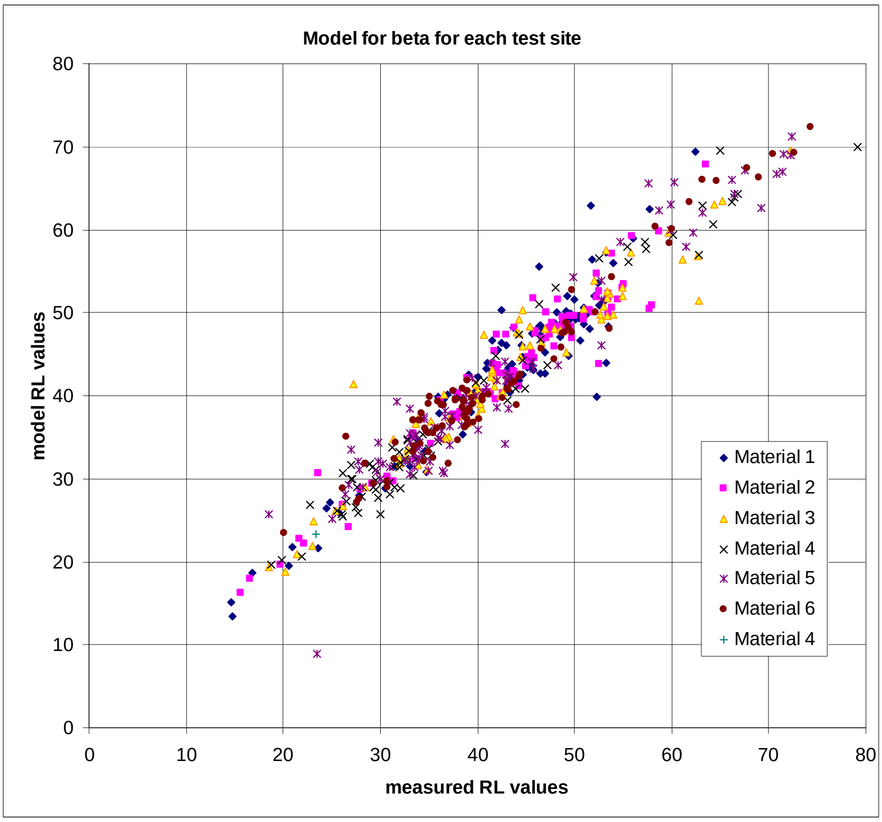


Figure D2: Correlation between measured β values and model β values based on individual sensitivities of the materials.

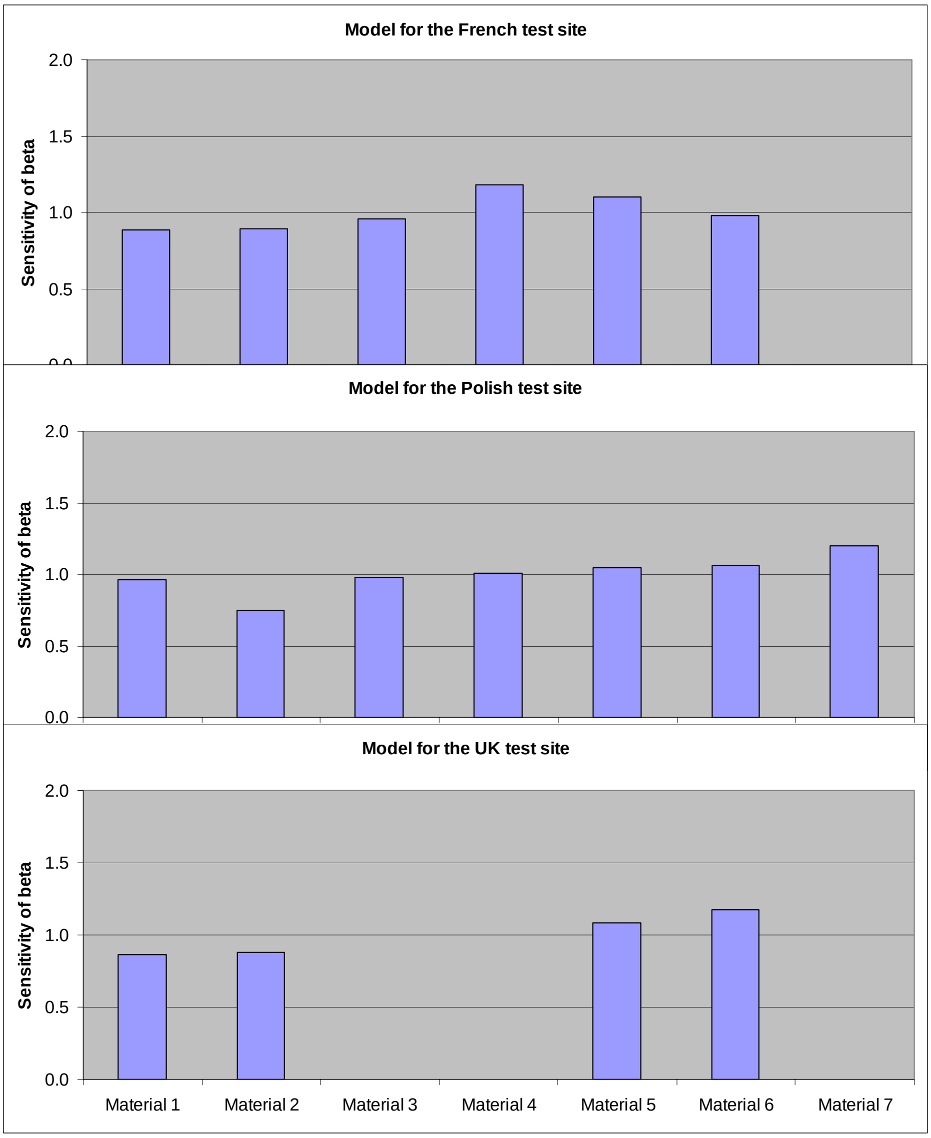


Figure D3: Sensitivity distributions for some road trials with similar distributions.

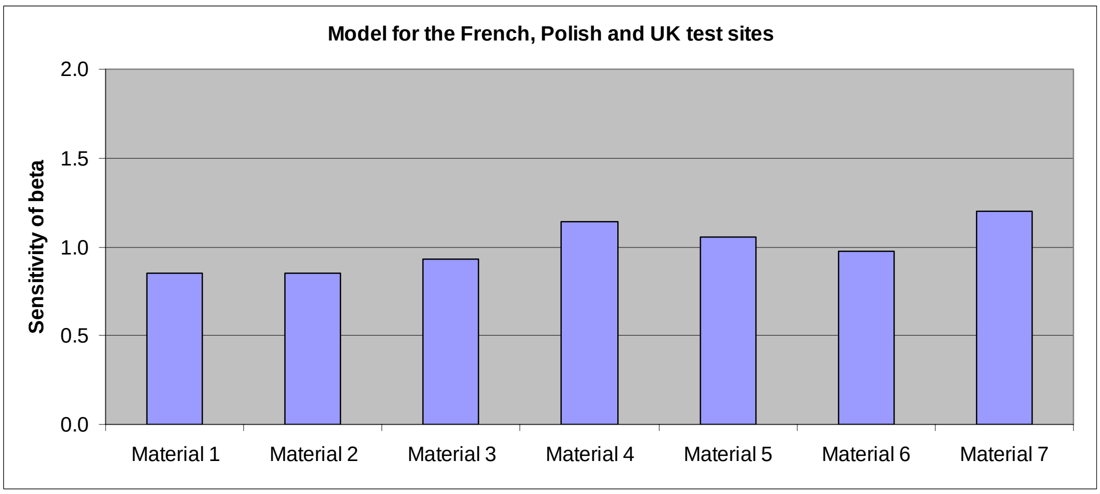


Figure D4: Single sensitivity distribution for some road trials.

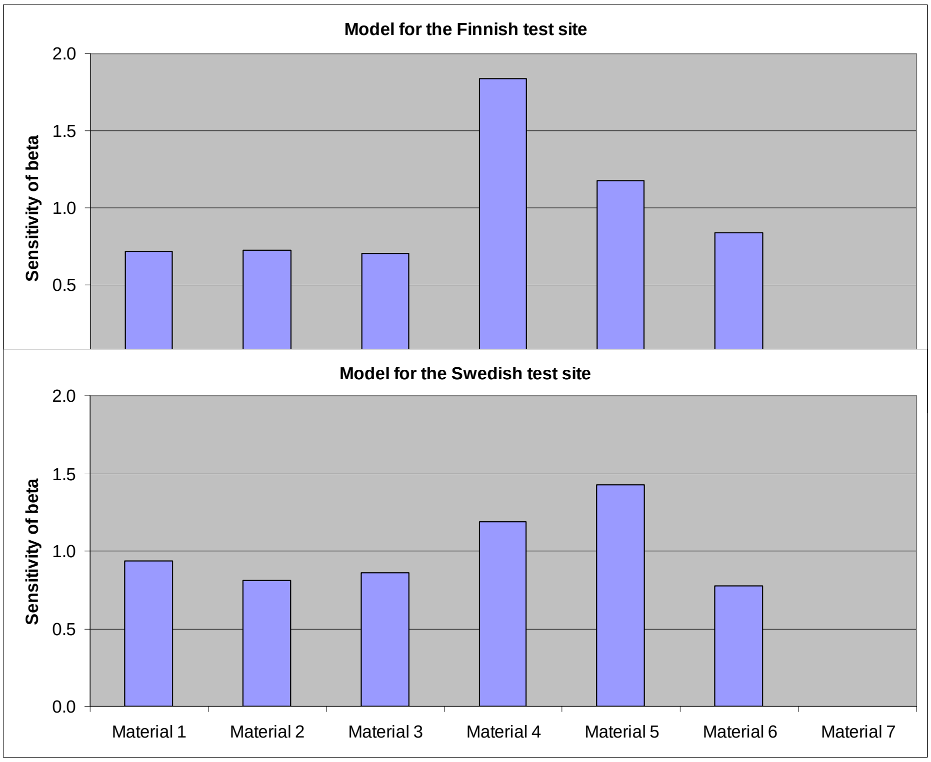


Figure D5: Sensitivity distributions for the Finnish and Swedish road trials.

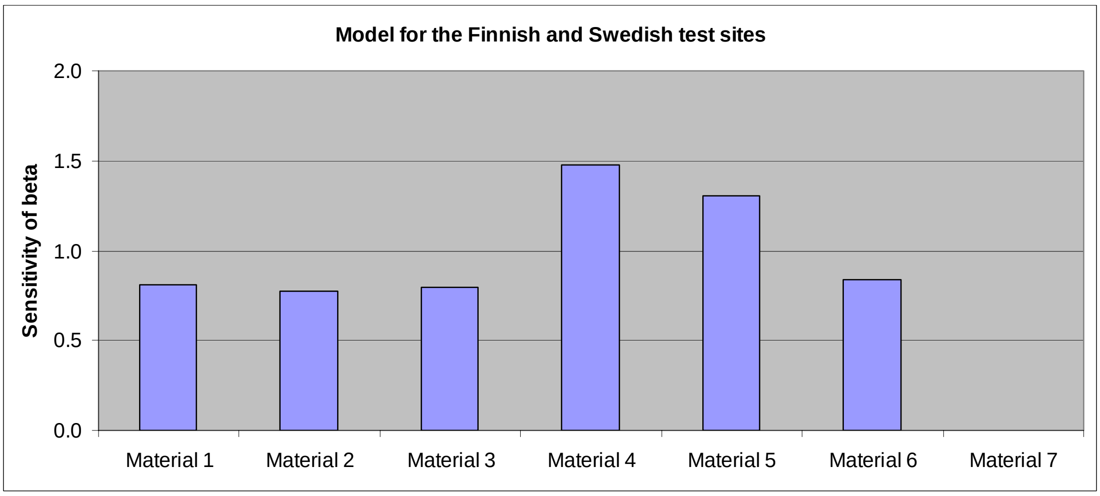


Figure D6: Single sensitivity distribution for the Finnish and Swedish road trials.

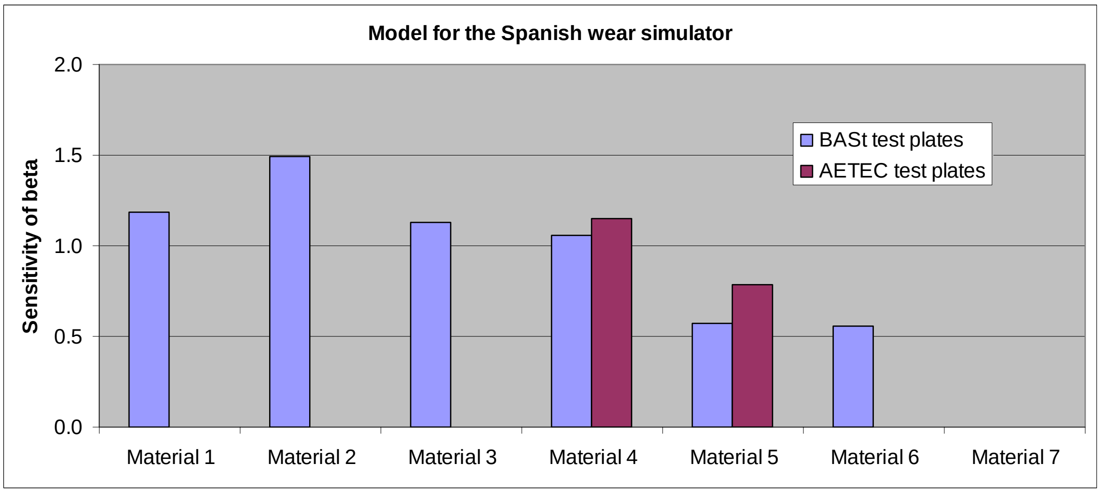


Figure D7: Sensitivity distribution for the Spanish wear simulator.

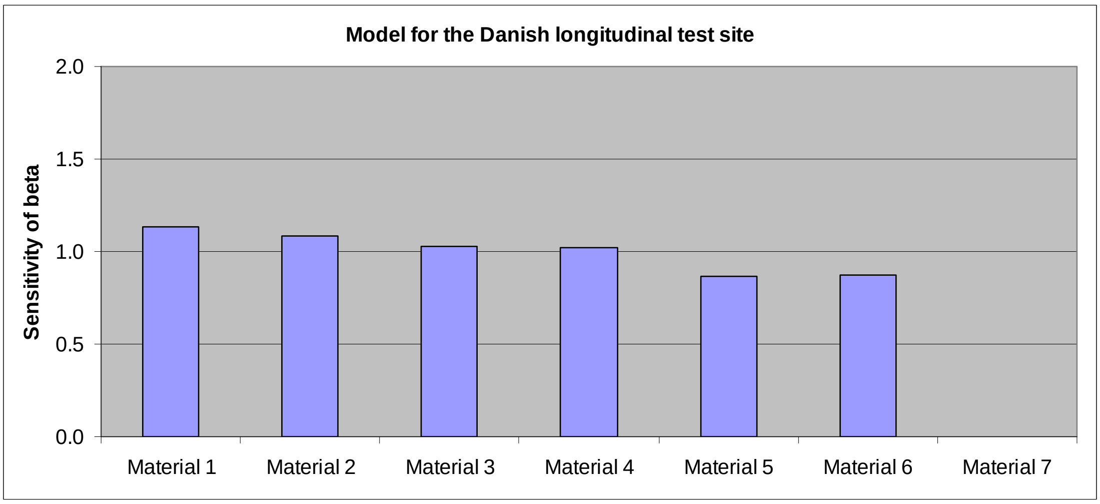


Figure D8: Sensitivity distribution for the Danish longitudinal road trial.

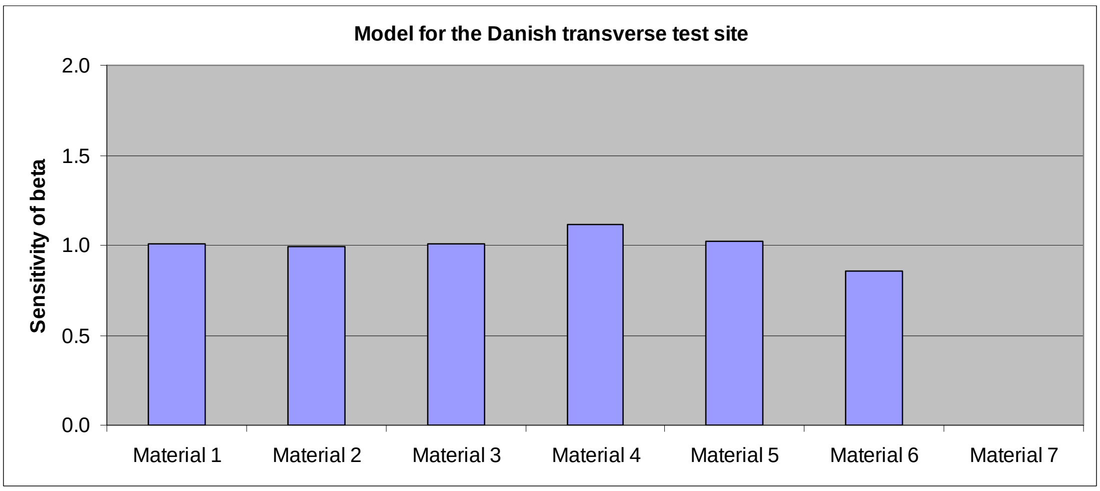


Figure D9: Sensitivity distribution for the Danish transverse road trial.

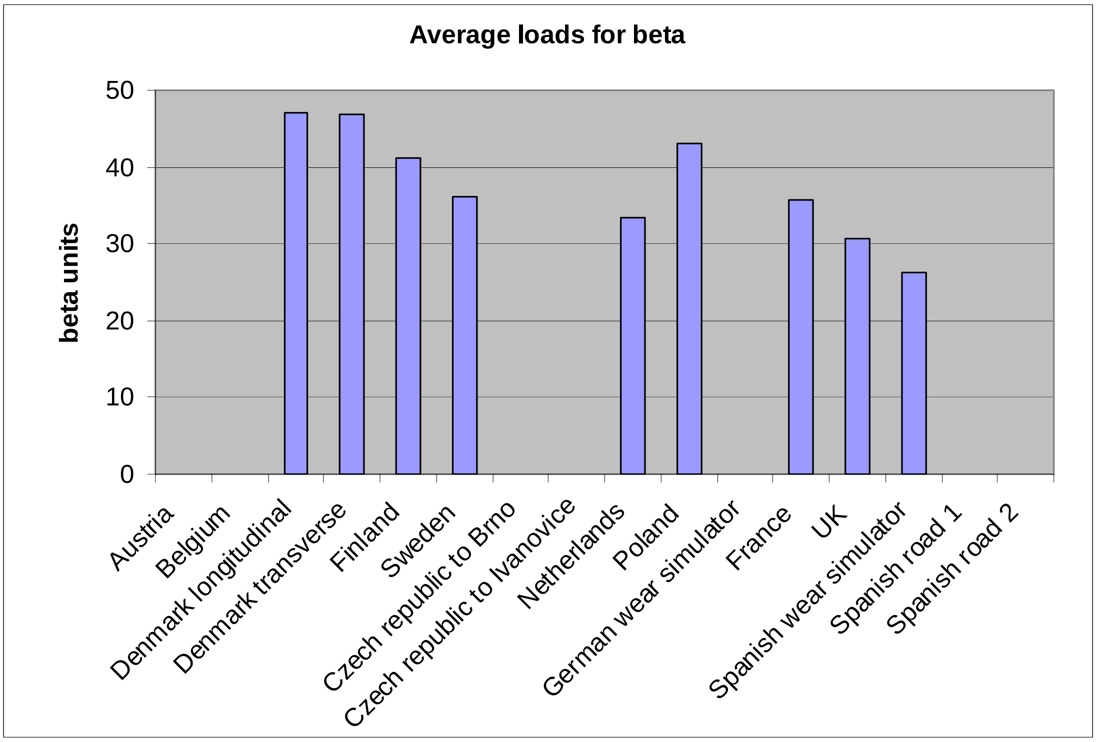


Figure D10: Average load factors for the β values.

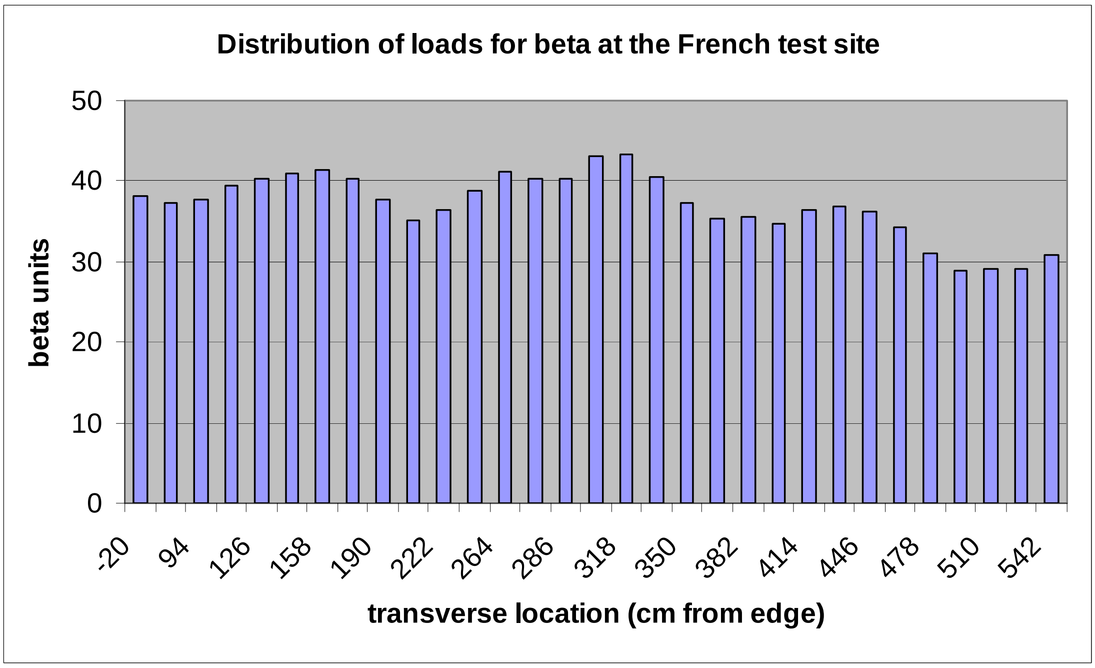


Figure D11: Variation of the load factor for the β values across the French road trial.

Annex E: Models for SRT values

E.1 Use of the SRT values

The measured SRT values show considerable variation with the materials, the test sites and the transverse locations on the test sites. Model methods according to annex A should therefore be useful.

The initial or potential SRT values to be used in the models have been set to 80 for all materials.

SRT values have mostly a limited variation within a factor of two. With such a variation, it is not crucial to decide if the model methods are to be applied on values directly or on logarithmic values. As the most simple, the SRT values have been used directly. This corresponds to the understanding that measuring uncertainty, repeatability or reproducibility of experiments is expressed directly in SRT units.

The SRT values in those positions, where R_L values were omitted from the analyses (refer to annex B), have also been omitted from the SRT analyses.

E.2 Constant or individual sensitivities of the materials

Figure E1 shows the correlation between measured SRT values and model SRT values, when the model is based on constant sensitivities of the materials - meaning that the materials have individual sensitivity values, but the same values for all test sites.

The correlation is rather poor, with a standard deviation of 6,6.

> NOTE: Twice the standard deviation is 13,2, which means that 95% of model SRT values are within ±13,2 of the measured SRT values.

Figure E2, on the other hand, shows the correlation, when the materials are allowed to have individual sensitivities - meaning that the values can be different for the different test sites/wear simulators.

This correlation is better, with a standard deviation of 3,7. The improvement is significant to a very high degree.

The assumption of constant sensitivities of the materials has, therefore, to be rejected and at least some individual variation between test sites has to be accepted..

E.3 More detailed comparison of the test sites

Figures E3, E4, E5 and E6 show the distributions of sensitivity of the materials, as derived in individual models the Belgian, French, Polish and UK road trial sites. These road trials are considered as a group in annex B, but in this case the distributions are obviously not similar, and therefore a single model for the four road trials has not been considered.

Figure E7 shows the individual distributions for the two road trial sites of the Czech republic, and figure E8 the distribution for a combined model. The standard deviation is 1,3 in both cases, which means that the combined model is acceptable.

Figures E9 and E10 show the distributions for the Finnish and Swedish road trial sites. These road trials are considered as a group in annex B, but in this case the distributions are obviously not similar, and therefore a single model for the two road trials has not been considered.

Figure E11 shows the individual distributions for the two wear simulators, and figure E12 the distribution for a combined model. The two models result in standard deviations of respectively 5,1 and 5,3. This difference is not significant, and small in any case. This means that the combined model is acceptable.

The distributions for the Danish longitudinal and transverse road trials are shown in figures E13 and E14. These two deviate fairly strongly from each other.

The distribution for the Netherlands road trial is shown in figure E15.

SRT has not been measured on the Austrian test site nor on the two Spanish roads.

E.4 Loads

Figure E16 shows the average loads for the different test sites. The average loads represent the average reductions of SRT values compared to the initial or potential value of 80; they range from 16 for the Danish transverse road trial to more than 40 for the wear simulators.

As an example of variation of the load at a test site, figure E17 shows the distribution of loads across the Danish longitudinal road trial site. Values are between 18 and 28 with an average of 22.

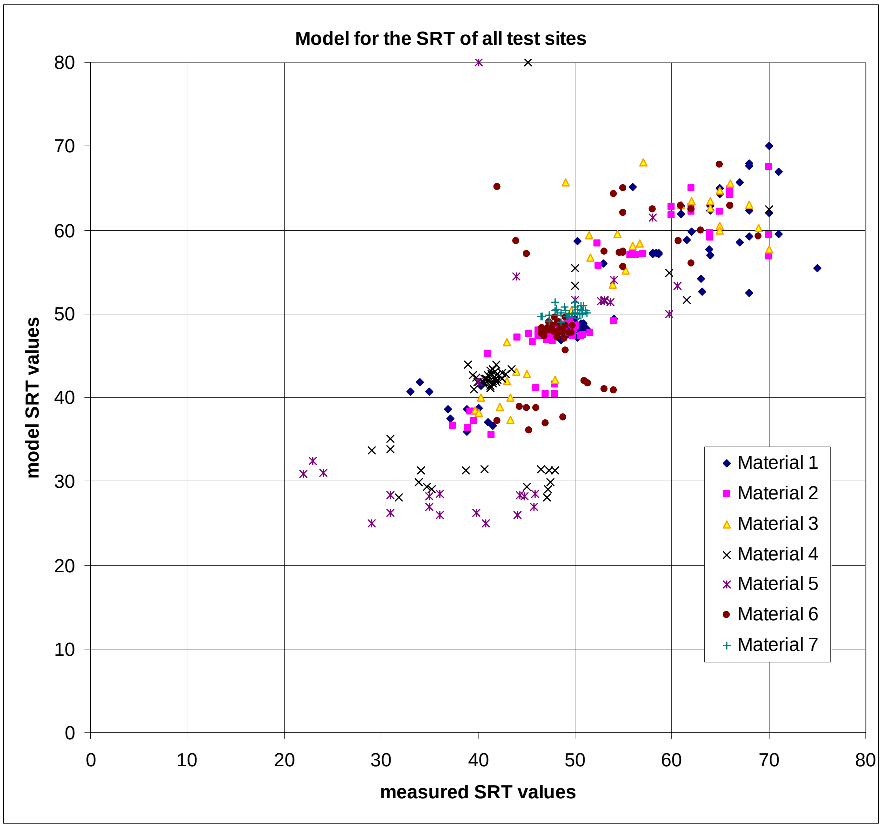


Figure E1: Correlation between measured SRT values and model SRT values based on constant sensitivities of the materials.

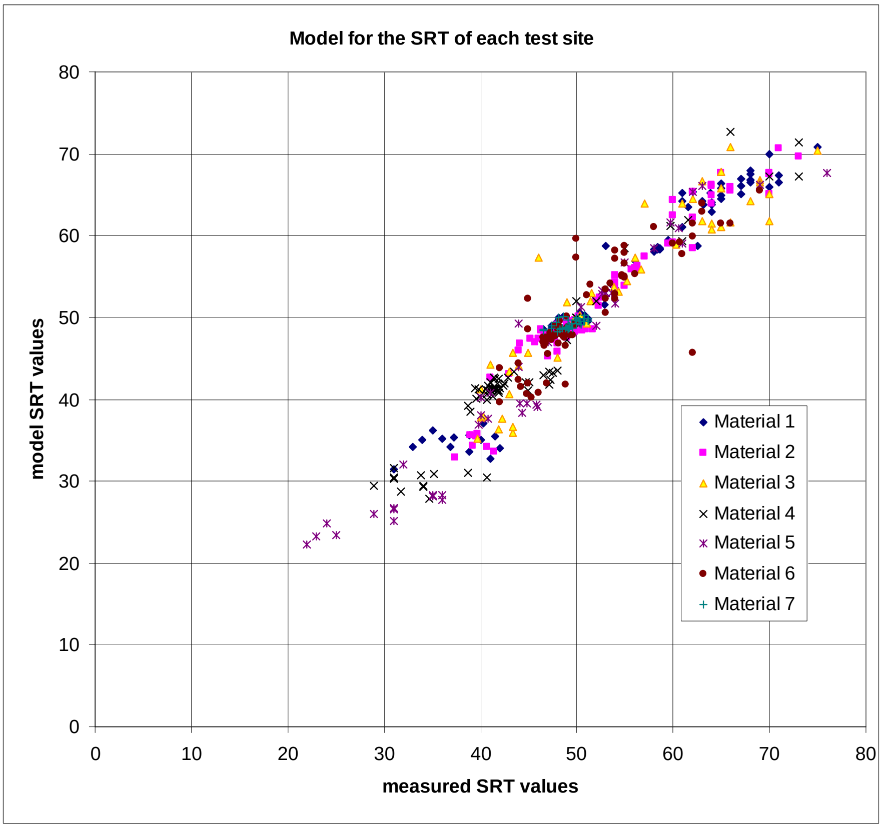


Figure E2: Correlation between measured SRT values and model SRT values based on individual sensitivities of the materials.

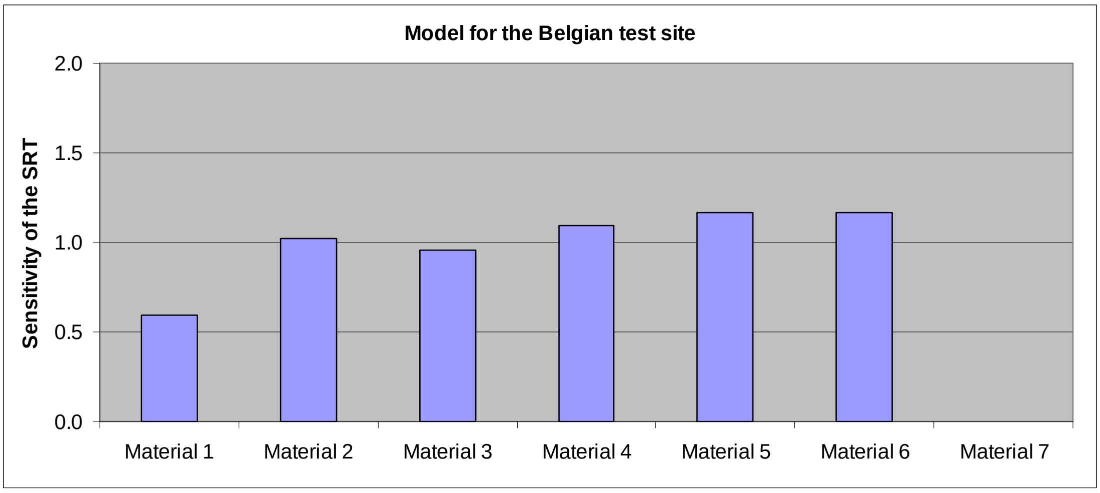


Figure E3: Sensitivity distribution for the Belgian road trial.

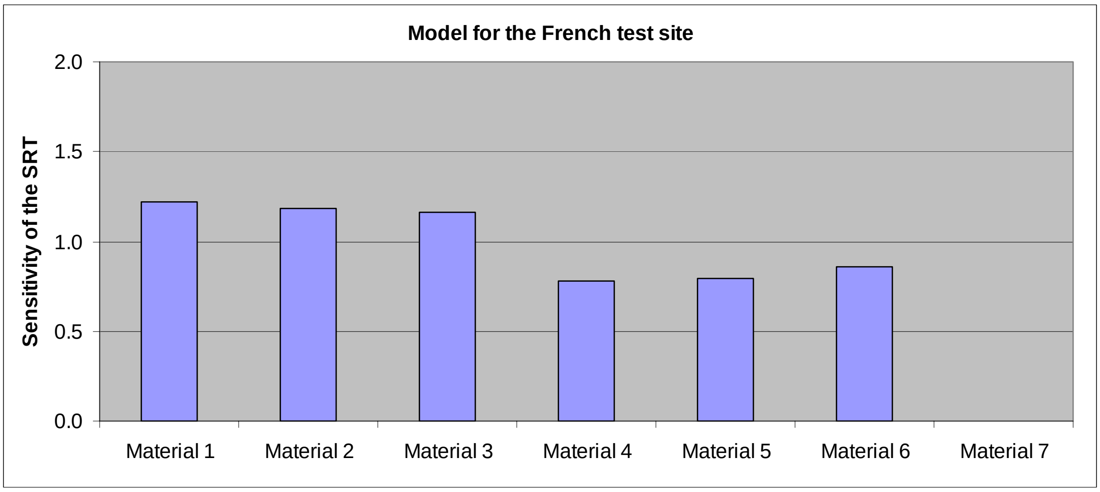


Figure E4: Sensitivity distribution for the French road trial.

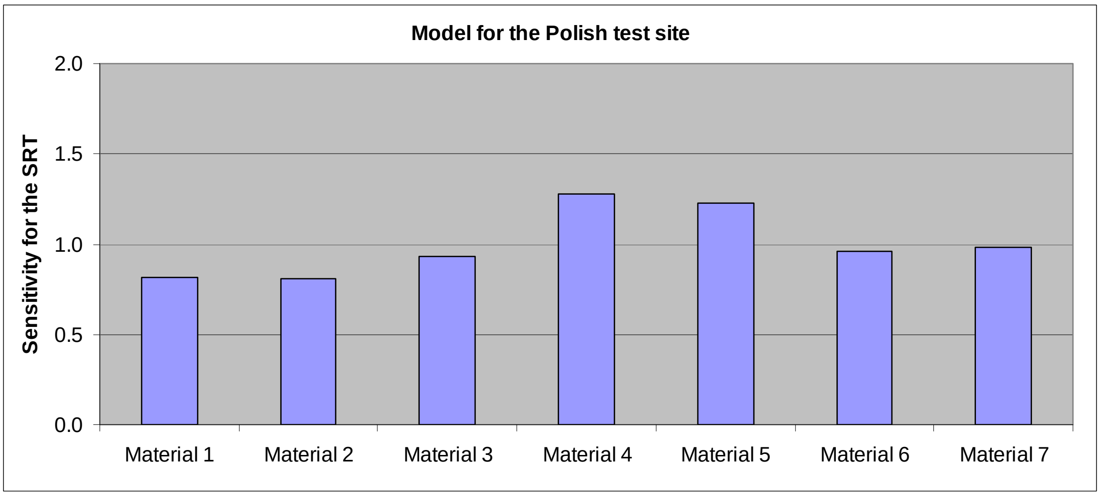


Figure E5: Sensitivity distribution for the Polish road trial.

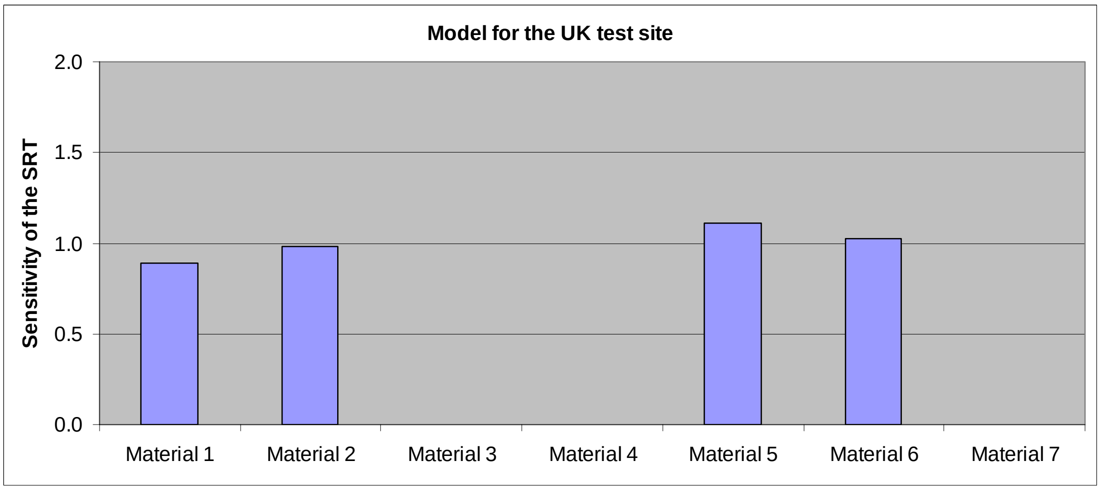


Figure E6: Sensitivity distribution for the UK road trial.

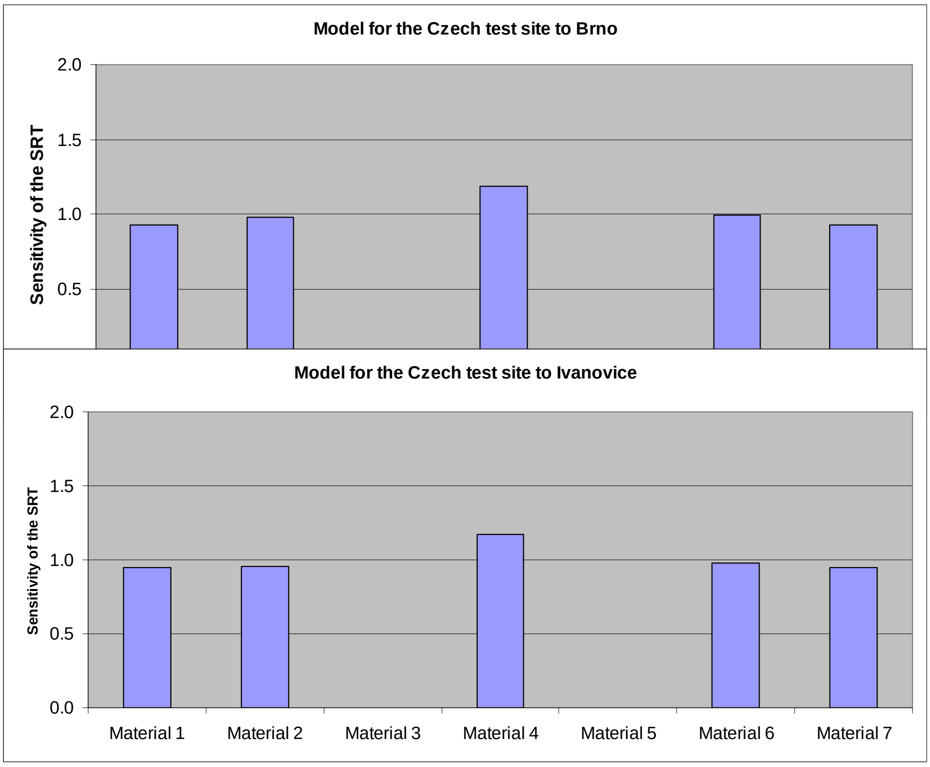


Figure E7: Sensitivity distributions for the two Check road trials.

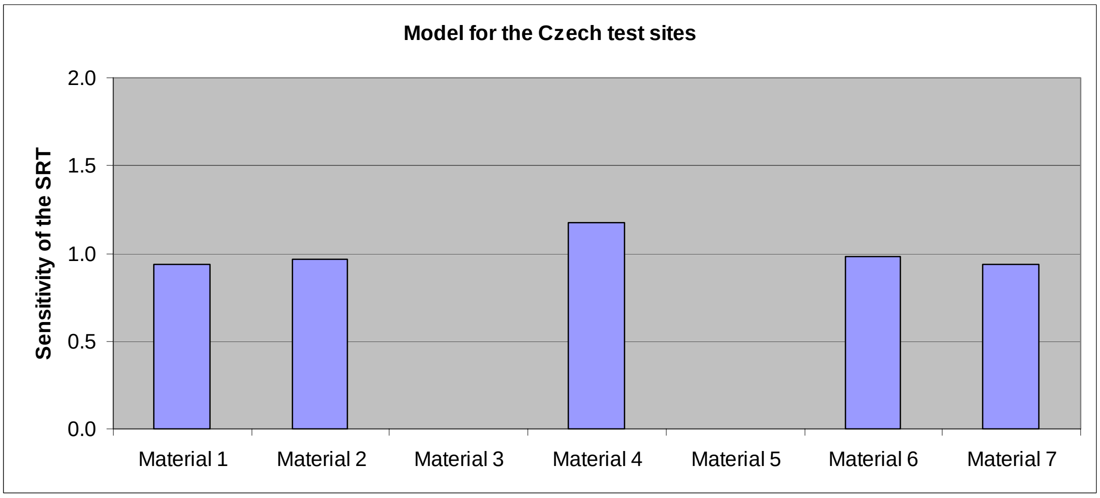


Figure E8: Single sensitivity distribution for the two Check road trials.

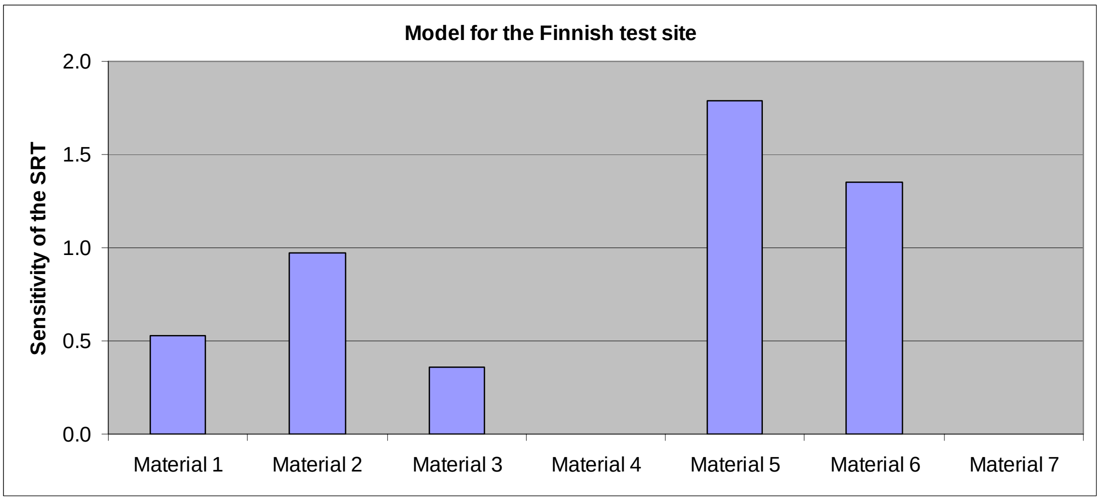


Figure E9: Sensitivity distribution for the Finnish road trial.

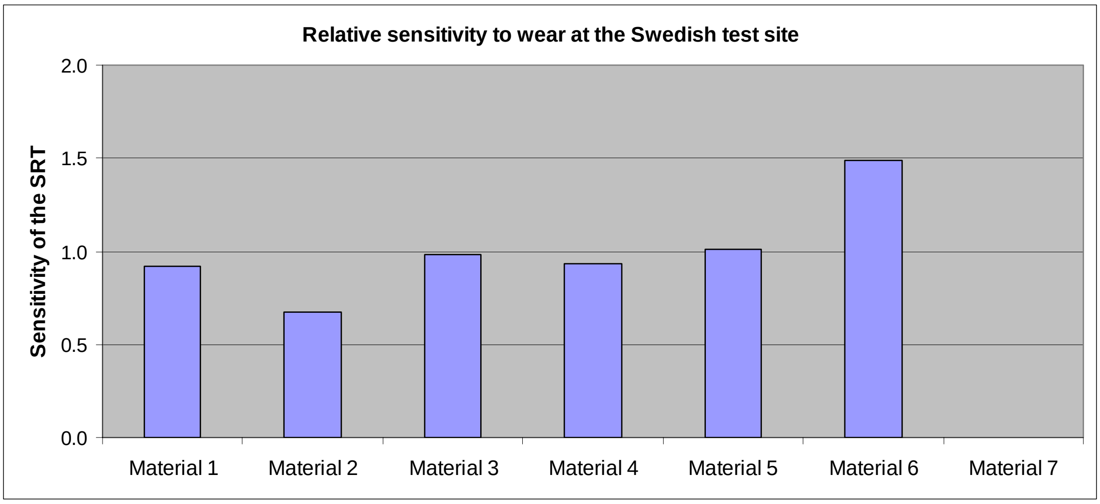


Figure E10: Sensitivity distribution for the Swedish road trial.

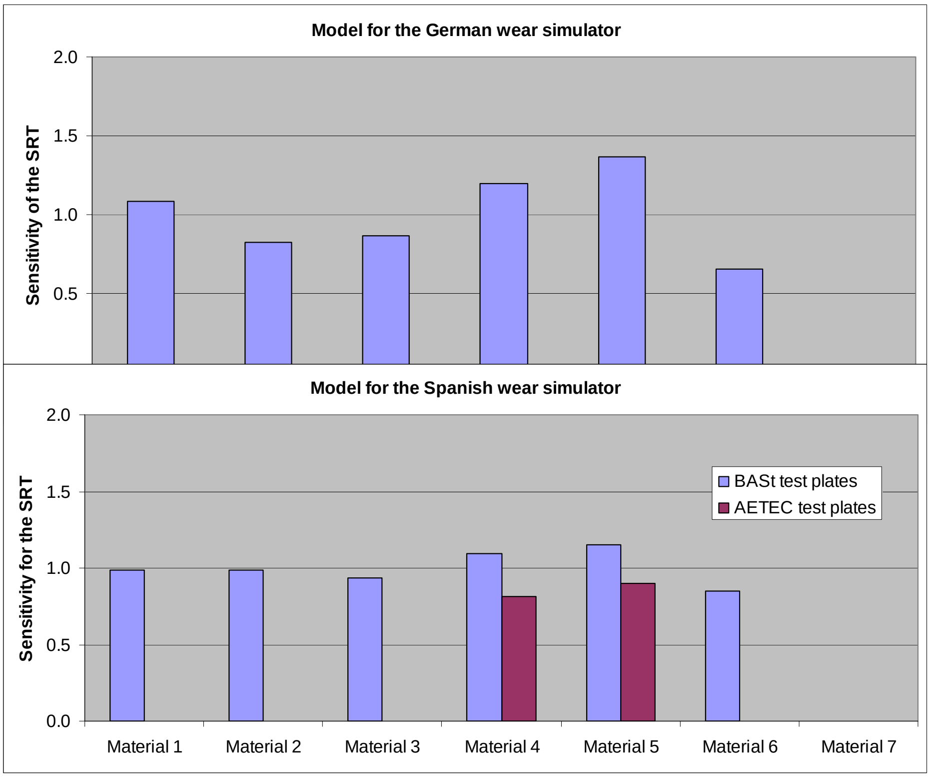


Figure E11: Sensitivity distributions for the wear simulators.

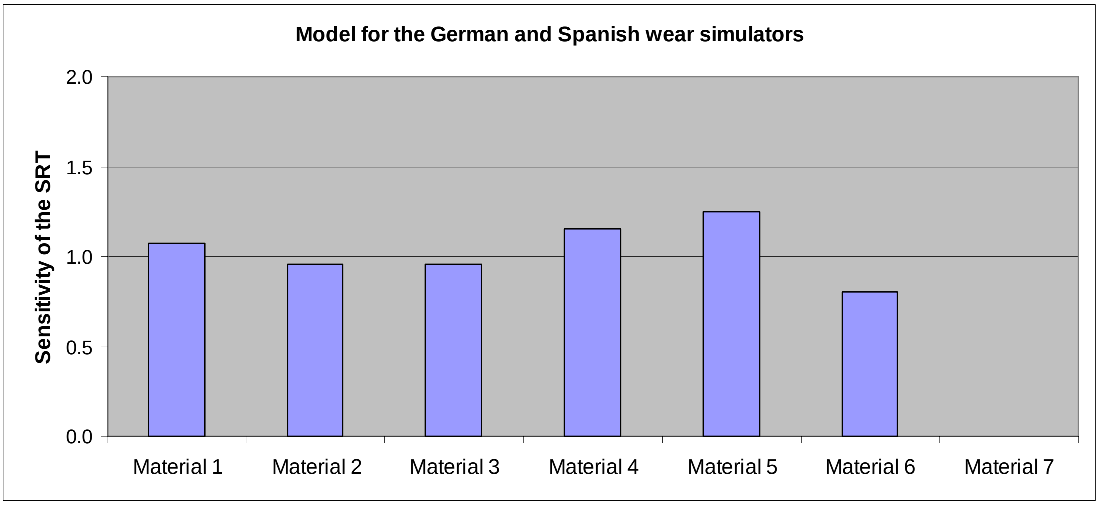


Figure E12: Single sensitivity distribution for the wear simulators.

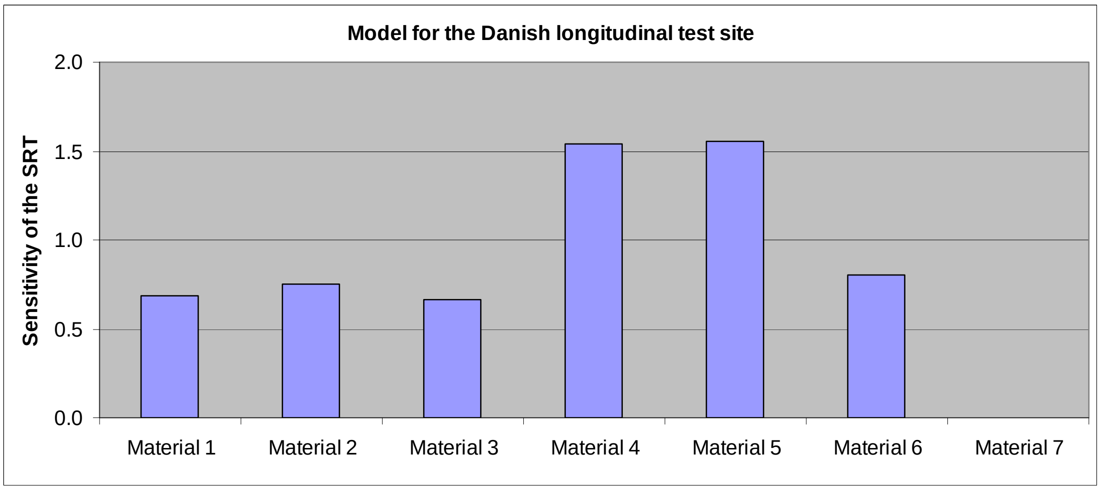


Figure E13: Sensitivity distribution for the Danish longitudinal road trial.

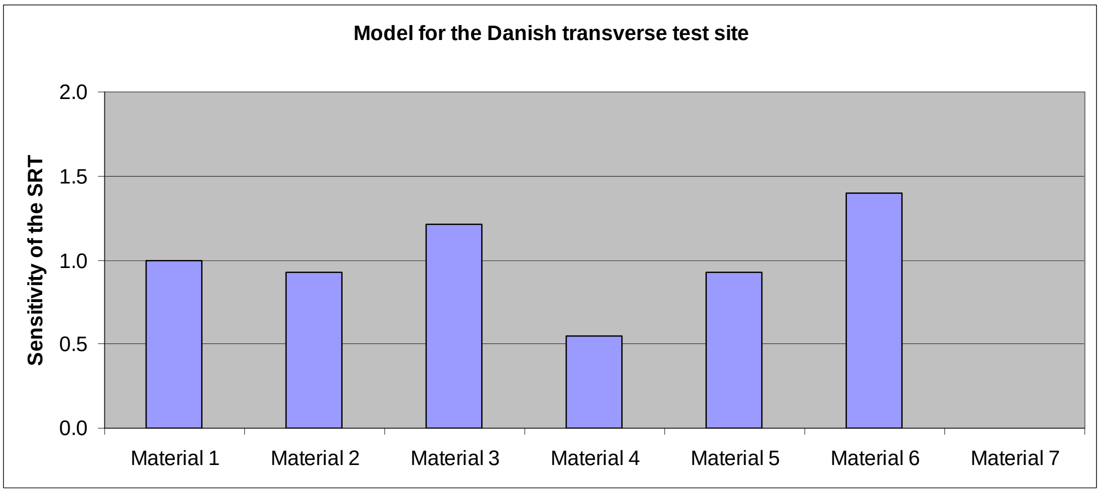


Figure E14: Sensitivity distribution for the Danish transverse road trial.

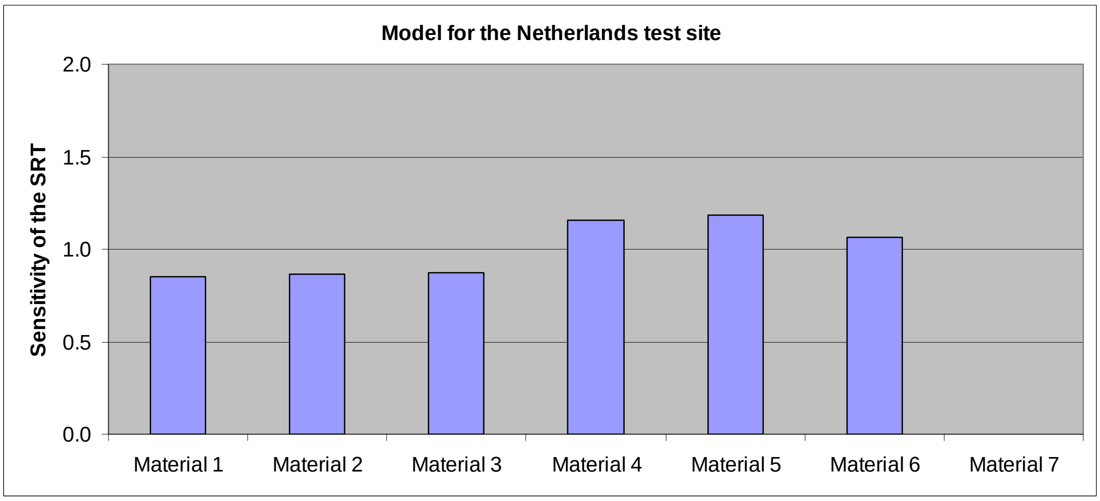


Figure E15: Sensitivity distribution for the Netherlands road trial.

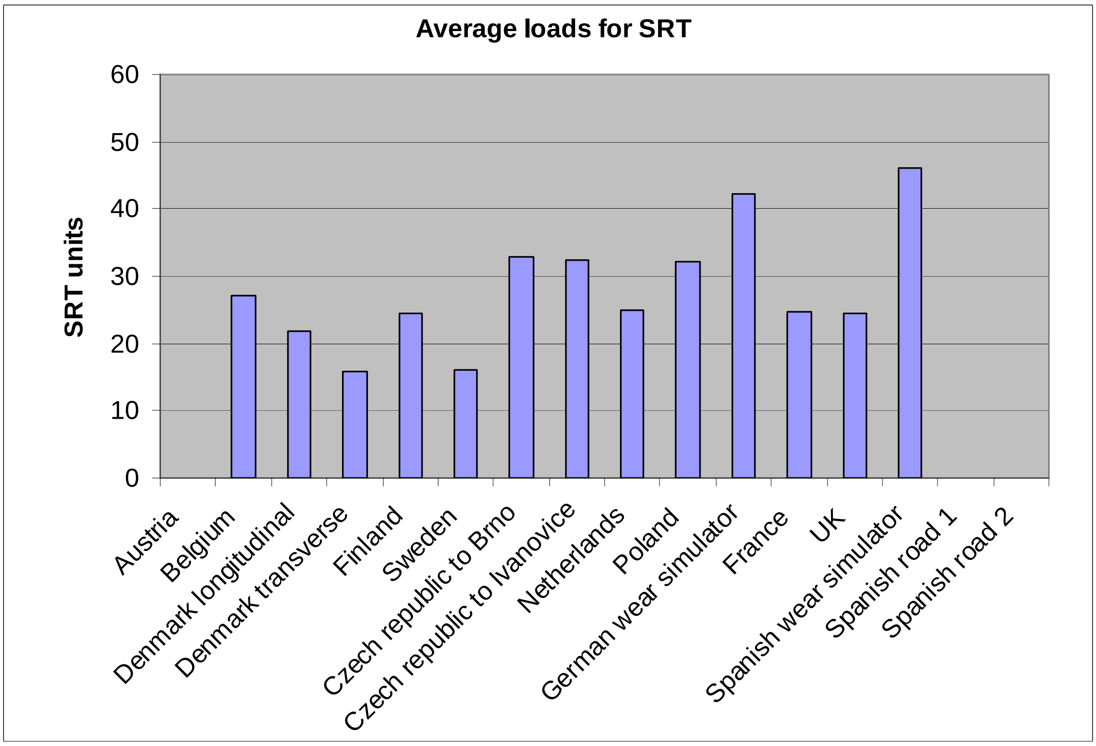


Figure E16: Average loads for the SRT values.

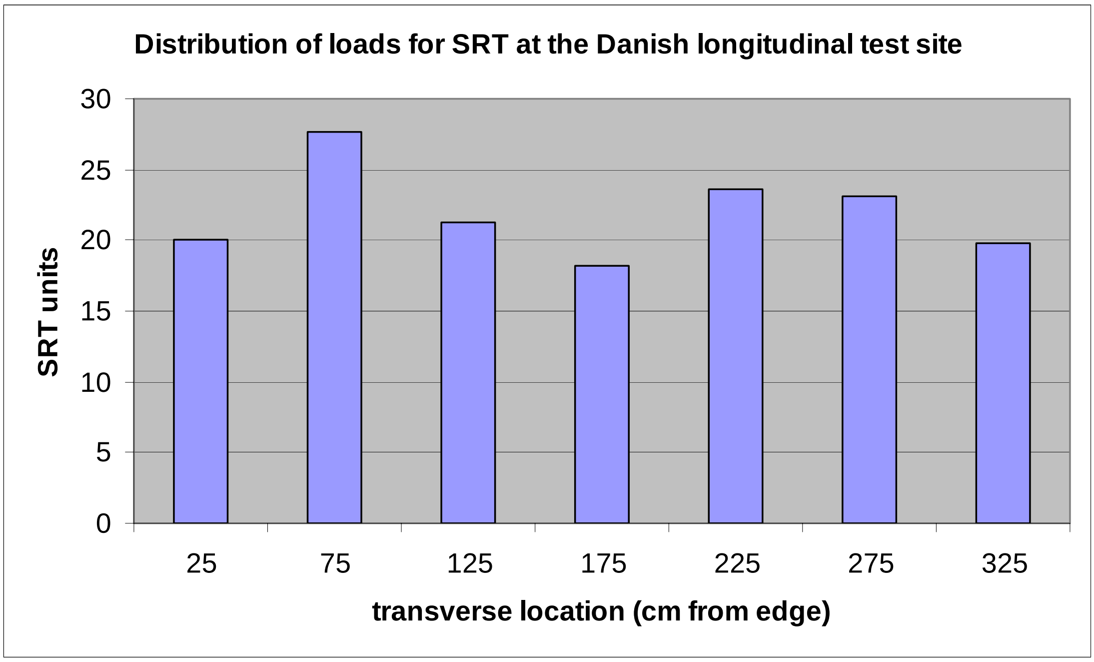


Figure E17: Variation of the loads for the SRT values across the Danish longitudinal road trial.