Gröna Tåget

Green Train

Comfort evaluation of active secondary suspension

OSKAR FRÖIDH
KARL KOTTENHOFF
JENNIFER WARG

Stockholm 2013

KTH Railway Group

www.gronataget.se
www.railwaygroup.kth.se

KTH Royal Institute of Technology
Division of Traffic and Logistics
SE-100 44 Stockholm, Sweden

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KTH Royal Institute of Technology
Division of Traffic and Logistics
SE-100 44 Stockholm
Sweden

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Preface

The Green Train (in Swedish "Gröna Tåget") is rather unique as a research and development programme since it brings together both institutes of higher education, infrastructure managers, railway companies and train manufacturers in a common programme. Since its inception in 2005 the objective has been to develop a concept proposal for a new, attractive high-speed train adapted to Nordic conditions that is flexible for several different tasks on the railway and interoperable in the Scandinavian countries. The concept proposal can act as a bank of ideas, recommendations and technical solutions for railway companies, track managers and the manufacturing industry.

One of the ideas selected for development is active secondary suspension. Bombardier Transportation, Sweden, has with support of KTH designed and tested both active lateral suspension (ALS) and active vertical suspension (AVS) that can improve the ride comfort and make higher speeds possible on existing tracks. The two active suspension systems were evaluated with passengers to allow KTH Railway Group to capture their perceived differences in ride comfort. In parallel with KTH's study, Bombardier Transportation evaluated the dynamic behaviour of the train. Contact persons at Bombardier were Henrik Tengstrand, Olaf Kämmerling (field test leader), Jakob Wingren and Rickard Persson.

From KTH Railway Group, Division of Traffic and Logistics, Karl Kottenhoff and Oskar Fröidh (project leader) performed the comfort evaluation. Jennifer Warg participated in questionnaire development and evaluation, and assisted in the survey and recruitment of respondents for the tests.

Stockholm, October 2013

Oskar Fröidh

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1. Introduction

1.1 Background

The Green Train research programme has devised a new high-speed train concept, primarily for operation in Scandinavia [1, 2]. One of the sub-systems in the concept is active secondary suspension. Active suspension can contribute to higher speeds with maintained comfort on track with less than perfect geometry. Alternatively, comfort can be increased or a lower track standard accepted at today’s speeds.

Active suspension has been developed jointly by KTH and Bombardier Transportation and the system has been described by, among others, Anneli Orvnäs, who participated in its development [3]. Active Lateral Suspension (ALS) has been in operation for a few years to gain experience of the systems in traffic with the project’s test train, Transitio’s Regina X50 9062, and now also exists for commercial use. Active Vertical Suspension (AVS) was installed on the test train in 2013. Both systems need to be studied with regard to travellers’ perceived comfort.

An evaluation of comfort measured with measuring instruments was made in parallel by Bombardier and is not reported here. Earlier research has shown differences between measured and perceived comfort and willingness to pay to improve the track geometry and thereby reduce vibrations [4, 5].

1.2 Aim

To investigate travellers’ perceived comfort with active secondary suspension (ALS/AVS) and obtain data concerning the possibility to increase the speeds of express trains, in particular in curves, on lines with imperfect track geometry, i.e. the normal state of conventional railway lines.

2. General design of the experiment

2.1 Method overview

Comfort with active lateral and vertical suspension has been evaluated with the help of test subjects (respondents). The subjects participated in two different situations: sitting in a seat and walking through the train. The intention was to assess the effects on comfort in the most realistic situations possible.

Comfort while seated was evaluated by means of printed questionnaires. The test subjects were asked to judge the quality of ride comfort during the journey along on the test section which took roughly half an hour to cover. The questions consisted of different ways of asking about comfort-related factors; see section 3.2. The test subjects were also given the opportunity to state whether there had been any momentary disturbances or other problems during their journey.

2.2 Combination of different tasks

To reduce the focus on the train's movements and vibrations, the respondents were asked to perform another task. The task consisted of conducting an interview on train traffic delays and concerned another research project which is not reported here. The task required a certain degree of concentration and the intention was to divert passengers' attention away from the train's movements while they were to nonetheless react to and note down major deviations in comfort during their journey, e.g. severe track defects.

3. Tests with active secondary suspension

3.1 Pilot and main studies

The method described below was devised and tested during the course of two preliminary pilot studies in early and mid-May 2013. The pilot study was conducted in regular traffic on the Western Main Line between Stockholm and Skövde, partly with different train types on the outbound and return journeys, X55 (SJ 3000, without carbody tilting, category B) and X2 (SJ 2000, with tilting, category S) in order to be able to compare the two to some degree.

The main study was conducted over two days, 28-29 May, with a total of four round trips between Stockholm and Hallsberg.

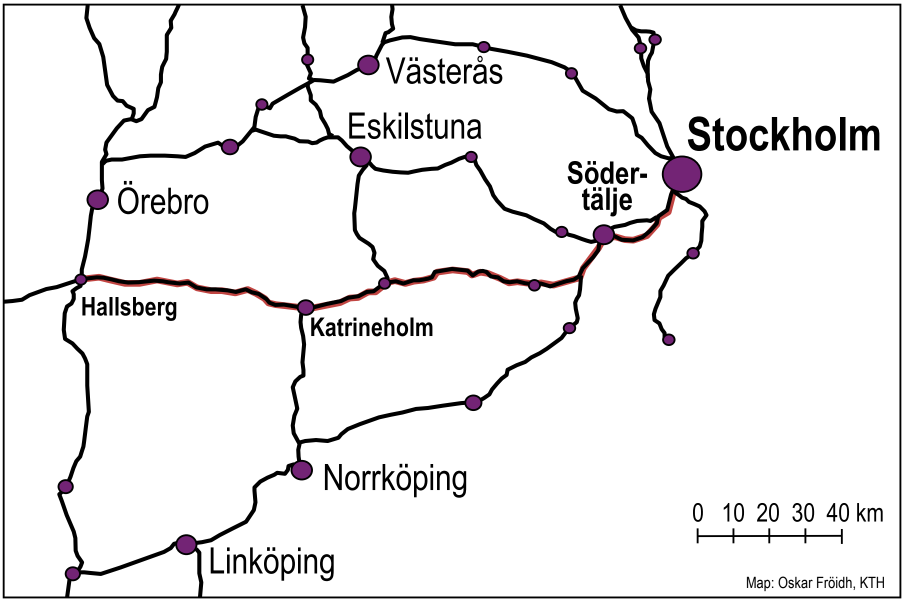

Figure 1. The main study was conducted on the Western Main Line between Stockholm and Hallsberg (bold line).

Figure 2. The test train, Regina X50 9062, in Hallsberg.

Table 1. Investigations conducted

Study	*Date*	*No. of respondents*	*Section*	*Train types*
Pilot study 1	06/05/2013	126 travellers interviewed	Stockholm–Skövde and back	X55 (56 travellers) and X2 (70 travellers)
Pilot study 2	20/05/2013	114 travellers interviewed	Stockholm–Skövde and back	X2 (56+58 travellers)
Main study	28/05 and 29/05/2013	204 interviews (2 interviews each with 102 test subjects)	Stockholm–Hallsberg and back	Modified Regina X50 9062

For the main study, test subjects were recruited from participants in the Green Train programme, through KTH's and KTH Alumni's websites and by means of personal information. The participating test subjects received a reward after the tests were completed in the form of two vouchers that can be redeemed for cinema tickets.

3.2 Structure of the interviews

A questionnaire was distributed at the beginning of the tests together with oral instructions about when to fill in different parts of the questionnaire.

The questionnaire contained background questions, among other things about their train travel and their proneness to travel sickness on various means of transport in addition to their socio-economic background. While the interview subjects on the pilot journeys were selected during an on-going journey, i.e. on their way to/from doing something, the test subjects in the main study were travelling solely for the sake of the study. To try to reflect a real situation, they were therefore asked to imagine that they were making a journey that took three hours and to choose between private or business as the purpose of their journey.

The actual assessments of how the ride comfort was perceived were divided into three parts (see also Appendix 2):

1. Perceived ride comfort, speed and travel sickness on fixed scales (with 7 levels, where the lowest represents poor/low/none and the highest good/high/strong).
2. Comfort, effort, noise level and hardness on a 100 mm ungraded scale. This was interpreted by measuring where the respondents' had marked the scale (0-100 mm). Low values indicate poor comfort and high values good comfort.
3. Question as to whether the ride comfort was perceived as sufficiently good. Binary answer (yes or no).

The intention of having three different methods was to increase the probability of capturing differences in perceived ride comfort between the different conditions according to the statistical design of the tests.

The test subjects were also asked to note down the times when they perceived problems such as strong shaking or too tight a curve and were given the opportunity to provide other comments. There were few travellers who made use of this opportunity in the manner intended. In the main study, where each interview subject made two trips, the difference between the trips was also evaluated.

Figure 3. Test subjects filling in their questionnaires.

3.3 Statistical design for the test runs in the main study

The tests in the main study were conducted on a two-car Regina train where car A was equipped with AVS/ALS and car B was not. Car B was always at the south end, i.e. the first car when travelling to Hallsberg, and car A at the north end, i.e. the first car when travelling to Stockholm.

Table 2. The tests were conducted over four journeys

	Morning	*Afternoon*
Day 1 (28 May)	Journey 1, outbound and home	Journey 2, outbound and home
Day 2 (29 May)	Journey 3, outbound and home	Journey 4, outbound and home

The test subjects were distributed between the cars in Stockholm at the beginning of each journey (groups 1 and 2) and were switched to the other car for the return journey, i.e. those who had travelled in car

A moved to car B and vice versa. This allowed all the test subjects to travel both with and without ALS/AVS.

The trains were operated according to a predetermined plan so that the system's effects could be evaluated at different speeds with corresponding cant deficit category B (150 mm) with the applicable speed profile according to the route book and increased speed in curves as "category C"; see Appendix 1.

Table 3. Design of test related to the four journeys

Journey	*Speed, category*	*Group 1[1]*	*Group 2[1]*
1a, outbound	B (150 mm)	Car A with ALS/AVS	Car B (standard)
1b, home	C (183 mm)	Car B (standard)	Car A with ALS/AVS
2a, outbound	C (183 mm)	Car A with ALS/AVS	Car B (standard)
2b, home	B (150 mm)	Car B (standard)	Car A with ALS/AVS
3a, outbound	C (183 mm)	Car A with ALS/AVS	Car B (standard)
3b, home	B (150 mm)	Car B (standard)	Car A with ALS/AVS
4a, outbound	B (150 mm)	Car A with ALS/AVS	Car B (standard)
4b, home	C (183 mm)	Car B (standard)	Car A with ALS/AVS

[1] The travellers were divided into two groups for each journey.

3.4 Pilot study test results

A total of 240 test subjects took part in pilot studies 1 and 2. The average grades in the different tests are presented briefly below and should be viewed only as a background to the tests in the main study.

The pilot study was conducted on the X55 and the X2 (see Table 4). A variance analysis (ANOVA) to determine any differences in perceived comfort shows that the two train types are perceived to be equal, and the differences that exist are small and not significant. The only exception is as regards speed: the respondents perceive the speed to be higher on the X55.

Table 4. Mean of interviewees' assessments of different factors

	X55	*X2*
Ride comfort (on a scale from 1 to 7)	5.07	4.94
Speed (on a scale from 1 to 7)	5.33	4.92*
Travel sickness (on a scale from 1 to 6)	1.22	0.82
Comfort	61.3/100 mm	60.8/100 mm
Effort	60.9/100 mm	57.5/100 mm
Noise	53.2/100 mm	53.8/100 mm
Hardness	52.3/100 mm	51.5/100 mm
Sufficient comfort? (Proportion stating yes)	83%	82%

* 95% significance. Other differences are small and not significant.

3.5 Test results with active secondary suspension and higher speed

102 test subjects took part in the main study and made two journeys each, giving 204 interviews about ride comfort on each round trip. The test subjects switched cars for their outbound and home journeys, allowing each person to travel both with and without ALS/AVS.

Table 5. Proportion of "no" responses to the question of whether comfort was sufficient

	Speed profile B	*Speed profile C*
Car A (ALS/AVS)	10%	15%
Car B	14%	20%

It can be seen from the table that 20% of the respondents in car B felt that comfort was insufficient when the train was running at speed profile C. When it was running more slowly, at speed B, 14% considered ride comfort to be inadequate. At speed C, an equivalently lower proportion are dissatisfied when ALS/AVS is in operation. The journey was perceived as even more comfortable at speed B with ALS/AVS, with only 10% dissatisfied with the ride comfort. In all, 13% felt that ride comfort was inadequate in car A (with ALS/AVS), compared to 17% in car B.

Regarding the question of which car the test subjects perceived as most comfortable, 17% answered "don't know". It was found that the speed profile for the journey had a great impact in this respect. It should be observed that each test subject tested only two of the four combinations and this may have affected their responses.

Table 6. Percentage stating a particular car as most comfortable

	Speed profile B	***Speed profile C***
Car A (ALS/AVS)	33%	38%
Car B	44%	33%

The stepwise scale from 1 (poor) to 7 (good) showed that ride comfort on the test train was perceived to be 5.7 at speed B and without ALS/AVS. With active suspension, comfort increased by 0.36 points. Some of this gain (0.20) disappeared at speed C. It would therefore seem that higher speed can be adequately compensated for by means of active suspension.

Table 7. Results of regression analysis of ride comfort grades

Comfort grade[1]	**5.27**	
Active secondary suspension	+0.36 (Total **5.63**)	significant (>95%)
Speed profile C	-0.20 (Total **5.43**)	significance = 87%

[1] Ride comfort on the test train as a dependent variable and active suspension and threshold speed as independent variables.

The table also shows the comfort grade with active suspension without threshold speed (category B) and the combined effect of threshold speed (category C) and with active suspension. The diagram below (Figure 4) shows the corresponding comfort grades.

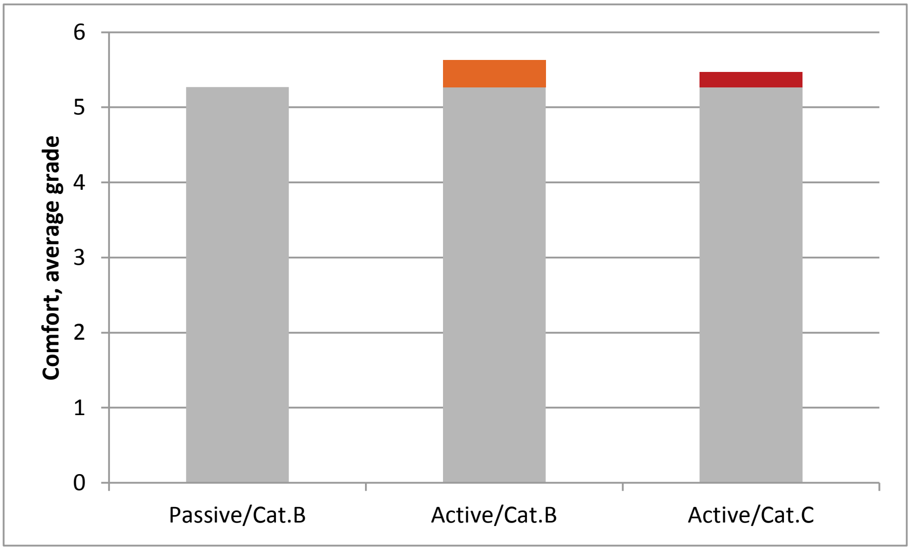

Figure 4. Ride comfort grade under different conditions (see text). The upper, orange or red, portion of the bars shows the increase in ride comfort perceived to be due to active suspension.

Table 8. Means and results of significance test (variance analysis)[1]

Question on	***Standard car***	***with AVS/ALS***	***Sign.***	***Speed B***	***Speed C***	***Sign.***
Mean grade						
Ride comfort	5.34	4.92	0.047*	5.22	5.05	0.431
Speed	4.91	5.00	0.660	4.75	5.16	0.041*
Travel sickness	0.40	0.38	0.849	0.35	0.43	0.488
Grade in mm on 100 mm scale						
Comfort	65.4	61.2	0.108	65.6	60.9	0.071
Effort	66.2	59.3	0.007*	64.7	60.9	0.134
Noise	57.5	56.8	0.798	58.4	55.9	0.341
Hardness	56.9	52.7	0.110	55.3	54.4	0.719

[1] Means and results from the variance analysis (ANOVA) of the respondents' gradings. The figures show both the means of three question on a scale from 1 to 7 (1-6 for travel sickness) and the means of the indications on a 100 mm line and whether differences with and without AVS/ALS are significant.

* 95% significance or higher

The difference in grades is in most cases small and thus not significant. There are exceptions, however. With active secondary suspension (AVS/ALS) the ride comfort and effort grades increase significantly. At threshold C instead of B, comfort is graded lower. The difference, however, is not 95% significant but on the other hand 90%. The test subjects also feel that the train's speed is higher at speed C, which it was.

The binary question concerning the adequacy of the comfort was analysed using a logit model of the significance of different factors.

Table 9. Results of logit analysis of responses to question about adequate ride comfort

Factor and significance according to logit analysis (log.regr.)	
•AVS/ALS	Not significant
•Threshold speed C	Not significant
•Seated facing forward/backward	Not significant
Indirect indicators	
•"It's noisy"	Significant (95%)
•The train feels hard/is running heavily	Significant (99%)

The results of the logit analysis concerning the responses to the question about ride comfort show that almost no variables had such a strong influence on the travellers that they were significant. Only "It's noisy" and "The train is running heavily" appear to have influenced those who were dissatisfied.

In our opinion, the relatively weak levels of significance in the main study do not permit further segmentation of the responses by, for example, gender, purpose of journey, etc. All the results therefore refer to the 102 test subjects as a group.

4. Walking test

4.1 Walk along the centre aisle

Background and purpose

During the course of the tests with active secondary suspension, the test subjects were asked to perform a walking test; walk along the central aisle from one end of the car (approx. 20 m) and then turn round and walk back while the train was running. The subjects carried a glass half-filled with water in one hand and thus had only one free hand with which to grasp handles and other fittings while walking.

The aim of the walking test is to assess the travellers' on-board comfort when they need to move around the train while it is moving, for example to buy drinks and refreshments or visit the toilets. The method was developed for this particular series of tests and has not been used before as far as we know.

Figure 5. Interior from the test train, here car B.

The test train

The two cars differ as regards furnishing. Car A (which had active secondary suspension, i.e. ALS/AVS) has a flat floor and seats along its length in addition to in the two vestibules and a small toilet. Car B has a more spacious disabled toilet, which means that there are no seats for a considerable distance along the aisle and one of the two vestibules has a lowered floor with two steps up and down to facilitate boarding and alighting. These differences consequently correlate with the train's suspension system and their effects cannot be distinguished.

The test subjects

In all, 83 walking tests were conducted where as a rule the same test subjects performed the test twice; once on the outbound journey and once on the journey home. 23 (28 %) of the tests were made by women. The age distribution was also skewed; the predominant age groups were 19-32 and 58-70, with an average age of 48.

The test subjects' physical mobility was assessed during the test on a scale from 1 to 5, where 5 represents good mobility. 55% of the tests were performed by test subjects with the highest mobility (5), 30% with the second highest (4) and smaller proportions by subjects with less mobility.

The way the test subjects progressed along the aisle was assessed by looking at how much they used their free hand for *support* and assigning a value from 1 to 5 where 5 represents not using their hand for support and 1 using their hand all the way along the aisle. A scale from 0-2 was used to assess how much they collided with objects along the way, where 0 means never and 2 often. *Collided* is an assessment of the number of times the test subject lost his or her balance and unintentionally bumped into seat-backs, door openings, etc in the aisle.

4.2 Results

Evaluation criteria

The results are described using three criteria: time, support and collided. The overall criterion *capability* was also evaluated but proved to correlate strongly with the test subjects' physical mobility and is therefore not presented further.

Average walking time was 53 s (both directions), with a minimum of 35 s and a maximum of 205 s.

Regarding "support", 2% of the tests were performed without the test subjects holding on to something with their free hand, 28% with support now and again, 43% with frequent support, 25% with support as a rule and the remainder (1%) with no support at all.

In the "collided"category, 42% of the test subjects managed the walk without bumping into seats, 52% had some collisions and the remaining 6% collided with seats or other objects several times.

Explanatory models

An analysis of correlations between the factors shows that the speed category factor, i.e. category B (150 mm) or category C (183 mm cant deficit), correlates significantly with "support" and "collided".

The test subjects' mobility correlates significantly with their age, walking time, capability, "support" and "collided". Walking time correlates significantly with the test subjects' age, mobility, capability, "support" and "collided". This has been used as confirmation of the model's applicability.

A linear regression analysis gives somewhat different models. When the dependent variable walking time is analysed, four explanatory variables are 95% significant: speed category, active secondary suspension, gender and mobility (see table 10).

Table 10. Regression model of walking time

Model parameter	***β***	***t***
(Constant)	101.9*	9.257
Speed profile	7.957*	2.031
Active secondary suspension	-11.38*	-2.903
Gender	8.647*	2.177
Mobility	-13.30*	-6.319

*95% significance

Dependent variable: Walking time

The presence of active suspension gives a model-estimated average shortening of walking time of 11 s, or -21%. This result correlates well with the cars' different interior designs. Increased speed and lateral acceleration from category B (150 mm) to category C (183 mm), on the other hand, give an 8 s (15%) longer walking time. Women need on average 9 s (16%) longer to perform the walking test while every higher level of the test subjects graded mobility reduces walking time by 13 s.

Regarding "support", two variables, speed category and mobility, give a significant (95%) explanation. The test subjects have consequently used their free hand for support more with increased speed from category B to category C, and more with reduced graded mobility. The presence of active suspension, on the other hand, does not give any significant results as regards the way of moving along the aisle. The "collided" factor gives similar results.

Table 11. Regression model of "support"

Model parameter	***β***	***t***
(Constant)	1.845**	4.223
Speed profile	-0.493**	-3.018
Mobility	0.334**	3.456

**99% significance

Dependent variable: "Support"

5. Discussion and conclusions

5.1 Seated tests

In the pilot experiments, the interviews were tested on the X2 and the X55, neither of which has active secondary suspension. Travellers perceived that speed was higher on the X55. This might be due to the X55 not having carbody tilting but there are also other differences as regards running characteristics and noise. It is surprising that ride comfort and/or "hardness" were not perceived to be better on the X2, which in the authors' opinion gives a gentle, comfortable ride, except for a small proportion of travellers usually experiencing some travel sickness.

The main study with higher speed and active suspension (ALS/AVS) showed that both factors are significant for some of the categories that the respondents were asked to assess. The primary purpose was to see whether active secondary suspension can compensate for the reduction in comfort that would otherwise result from an increase in speed. The test results show that this is the case.

It is interesting to note that the travellers actually feel the higher speed and that the perceived comfort formulated in the "comfort" concept is reduced. Active suspension thus increases "ride comfort", which is almost the same thing as "comfort". It is also interesting that the feeling of "effort" is clearly lower when active suspension is used.

5.2 Walking test

Active suspension has a positive effect on the time taken by the travellers to walk along the train when it is in motion. This, however, correlates with the cars' different interiors. The team that conducted the tests do not feel that the interior affected walking time to such a great extent, but rather the test subjects' technique for moving along the train was different in these sections of the cars. To determine the influence on walking time, the same walking tests would need to be conducted on a stationary train.

Subjects' way of moving forward changes with increased speed from category B to category C. At higher speed, they use their hand for support to a greater extent and lose their balance more often than at lower speed so that they collide with seats and other fittings. This shows that higher speed gives larger lateral accelerations, including jerks, which are difficult to counter.

The ability to counter lateral acceleration, however, can be most clearly explained by the test subjects' mobility. This means that any form of reduced mobility is a handicap on board a moving train and the handicap becomes more severe with increased while fully mobile people manage relatively well. Active suspension primarily reduces jerking but has only a marginal effect on the constant lateral acceleration in curves. For this reason it is an advantage from the point of view of comfort to keep the lower speed category (B) or higher speed in combination with tilting.

The higher speeds make great demands on the design of the train's furnishings, with handles to hold on to when moving around and other places to lean against on both sides of the aisle. The interior must also be so designed as to allow travellers to lose their balance without injuring themselves on sharp corners or stumbling.

5.3 Summarising conclusions

Our conclusion is that active secondary suspension (ALS/AVS) improves perceived comfort and makes it easier for passengers to move about the train while it is motion while an increase in speed (from category B to category C) has an opposite effect of approximately the same magnitude. This shows that active secondary suspension can contribute to permitting higher speeds on conventional lines with imperfect track geometry.

The higher uncompensated lateral force on bends resulting from higher speeds (category C), however, makes it significantly more difficult to move about the train for travellers with reduced mobility and this needs to be taken into consideration.

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Appendix 1. Speed profile for the test

Stockholm C – Hallsberg		
	The test train's speed profile	
*Kilometre post**	Cat. B (km/h) *Cant deficit 150 mm*	Cat. C (km/h) *Cant deficit 183 mm*
Stockholm Central (Cst): 0+000	30	30
0+250	80	80
3+247	100	100
3+550	120	120
10+200	160	160
16+607	195	200
20+128	200	200
36+866	150	165
Södertälje syd övre (Söö): 37+404		
37+945	185	185
45+095	195	200
46+166	175	185
54+840	165	170
60+300	150	165
93+000	150	160
115+725	175	185
132+370	150	165
Katrineholm Central (K): 133+934		
137+450	175	180
143+650	150	165
153+160	175	180
154+007	165	180
154+180	175	180
158+090	165	180
158+580	175	190
165+600	165	175
166+200	175	190
190+230	165	180
192+130	175	180
198+838	140	150
Hallsberg person. (Hpbg): 199+458		

Speed profile in the reverse direction similar with only minor differences.

* Might differ from real distances

Appendix 2. Interview questionnaire, travel comfort (first journey)

A few background questions about yourself

1. How often do you travel by long-distance or express train?

☐1 4 or more days a week ☐2 1-3 days a week

☐3 1-3 days a month ☐4 More seldom

2. How often are you travel-sick on/in a ... ? (on longer journeys)

	Never	Some-times	Often	Don't know
Bus	☐1	☐2	☐3	☐4
Car	☐1	☐2	☐3	☐4
Long-distance train	☐1	☐2	☐3	☐4
X 2000	☐1	☐2	☐3	☐4
Plane	☐1	☐2	☐3	☐4
Ship/ferry	☐1	☐2	☐3	☐4

Fictitious journey

Imagine that you are making this journey to a specific destination, i.e. choose a purpose that you can imagine yourself doing (for example the last journey that you made). The journey takes 3 hours.

3. What purpose do you choose?

☐1 Business trip - your employer pays your fare

☐2 Leisure or other private purpose

Car ☐1 A ☐2 B

Seat ______

Task to do between Södertälje and Katrineholm

4. We know that people appreciate the comfort on board express trains. Nonetheless, they still perceive problems at times. While you are travelling between Södertälje and Katrineholm, note down below if and when you are disturbed by poor comfort or if you have walked about the train or done something else.

Time(s) hr.min	**Sharp bend**	**Strong shaking**	**Walked about the train**	**Other**
Example: *13.35*		*X*		
Write below:				

Questions to answer at or after Katrineholm

5. How did you perceive the ride comfort in general after Södertälje?	**6.** How did you perceive the speed of the train?	**7.** Do you feel any travel sickness now? If so, how much?
Poor Good ☐ ☐ ☐ ☐ ☐ ☐ ☐ 1 2 3 4 5 6 7	Low High ☐ ☐ ☐ ☐ ☐ ☐ ☐ 1 2 3 4 5 6 7	None Severe ☐ ☐ ☐ ☐ ☐ ☐ ☐ 0 1 2 3 4 5 6

How did you perceive the ride comfort? Put one cross (X) on each line.

8.	extremely uncom-fortable	├───────────┼───────────┤	extremely comfort-able
9.	extremely strenuous	├───────────┼───────────┤	extremely restful
10.	extremely noisy	├───────────┼───────────┤	extremely quiet
11.	extremely hard	├───────────┼───────────┤	extremely soft

12. Overall, was the ride comfort adequate?

Yes ☐1 No ☐2

13. Was the ride comfort better on the outbound or homebound journey?

Better outbound ☐1 Better homebound ☐2 Don't know ☐3

A few background questions about yourself

14. Gender ☐1 Male ☐2 Female

15. Age ☐2 16-24 ☐3 25-44 ☐4 45-64 ☐5 65 or older

16. Marital status ☐1 Single/separated ☐2 Cohabitant/married

17. Children ☐1 No children living at home ☐2 Children living at home

18. Do you have access to a car? ☐1 Yes ☐2 No

19. What is your primary occupation?

☐1 Student ☐2 Retired

☐3 Employed ☐4 Other

☐5 Self-employed

20. What is your highest level of completed education?

☐1 9-year compulsory school or equivalent ☐2 Higher education institute/university

☐3 Upper secondary school or equivalent

☐4 Post-secondary school ☐5 Other

21. What is your household's monthly income before tax? **(By income is meant salary/wages, pension, study grant, payments from the National Insurance Agency, income from self-employment or agriculture)**

☐1 Up to 10,000 SEK ☐2 10,001 – 30,000 SEK

☐3 30,001 – 80,000 SEK ☐4 More than 80,000 SEK

Comments
22. **Comments on the ride comfort**
23. **Other comments**

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The Railway Group at KTH Royal Institute of Technology in Stockholm conducts interdisciplinary research and education in railway technology and train services. The aim of the research is to develop methods and provide knowledge that can develop railway transport and make the train more attractive to customers and more profitable for railway companies.

The Railway Group at the Division of Traffic and Logistics specializes in market, railway services and economy. Examples include transport planning, customer ratings, forecasting, market analyses concerning both passengers and freight, simulation models for railway capacity, system performance, and strategic planning of infrastructure. You can find more information at **www.railwaygroup.kth.se.**

A research and development programme called Green Train has been conducted from 2005 to 2013. The aim of the programme was to develop a new express train concept adapted for Scandinavian conditions and involved a large part of the Swedish railway sector. In this report from the Division of Traffic and Logistics at KTH, passenger ride comfort on a test train with active secondary suspension is evaluated. **www.gronataget.se**