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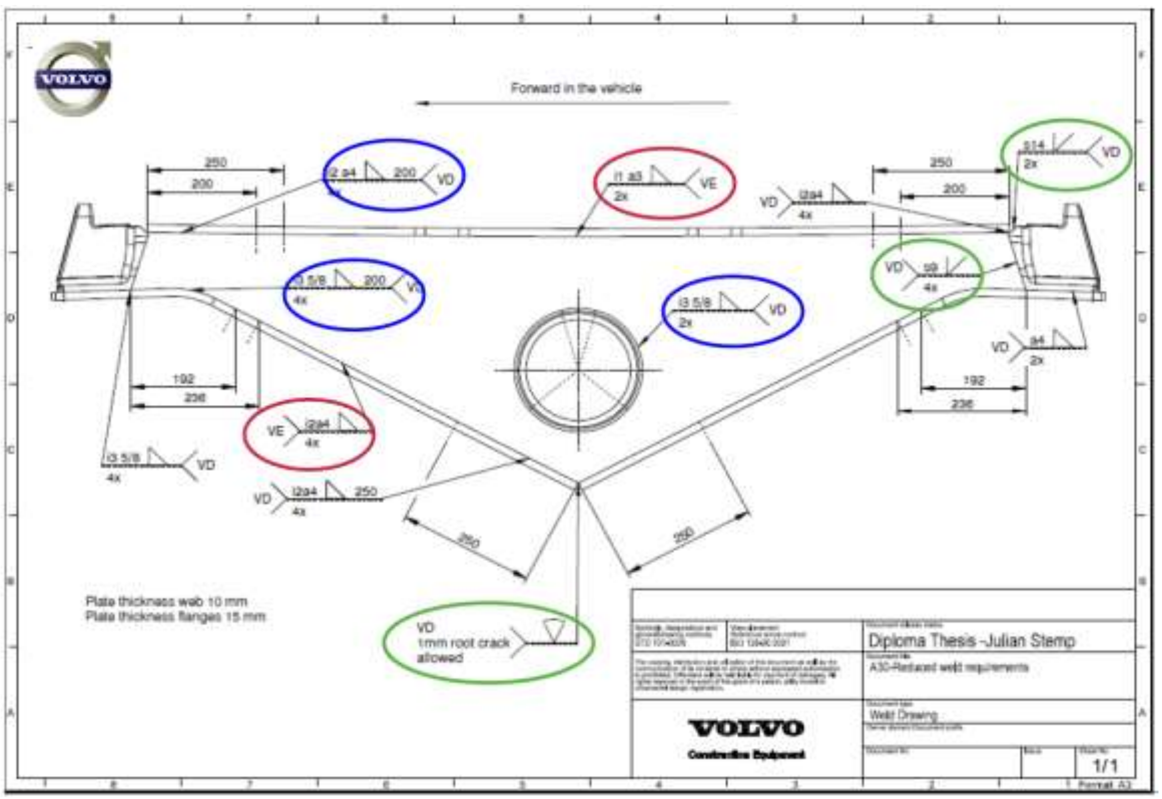
Final report WIQ - (diarie-no. 2009-04719) Public Report



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Innehåll

1. Summary

The goal of the project was to implement a new quality system for welding in design and manufacturing of welded components. The regulation in the new system is built to reflect fatigue using a principle of ”design and weld for purpose” contrary to earlier systems, Swedish as well as International, where ”good workmanship” is used. The task was to reduce the weight on load carrying welded structures with at least 20 % using the new system. And to seek answers to what is needed to do and what problems could arise. In a world where it becomes increasingly important to reduce material and fuel consumption, this is an important issue to maintain the progress compared to competitors. The project was divided into a number of work packages which contained different aspects but at the same time were strongly interconnected. The results were tested on a real component and it was shown to have a weight reduction of 24 % at the same time as reaching a tested fatigue life more than twice the current design, see fig 1.

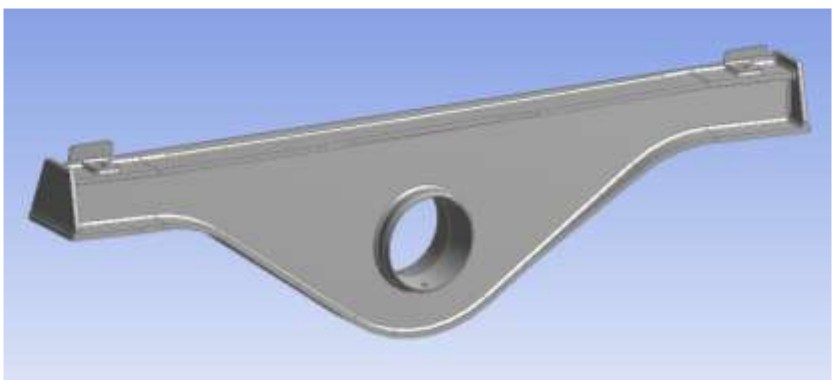

Figure 1 Tested real component, boggi-beam to a hauler

2. Background

During appr. the latest 20 years, a number of development projects have been performed within Volvo CE, where design of welded components was a theme. The first problem found was in the analysis part. At this time, the so called “nominal” method was used and it was shown to have bad accuracy. The problems were to correct assess the nominal stress level (sometimes impossible), to choose the appropriate Wholer-curve (sometimes non-existing) and also that the weld inside (root) could not be properly addressed. After that a number of different methods were tested around the millennium shift, the conclusion was to use so called “local” based methods. Here, using the FE-method, it was

possible to see directly which point(s) of the weld being critical and the accuracy of the life prediction was raised significantly.
Now, having an improved analysis method, the interest was directed towards the parameters governing the weld quality. As an example, there were a lot of discussions on the most important parameter on the outside, the weld toe transition radius (R). The radius was not regulated in the weld class system. Another point, to where the majority of the failures could be related, was the weld root point. Here, the penetration was extremely important, but this was not well governed on the drawing and could easily be neglected. So around 2005, a work was made to see how well the quality systems reflected fatigue. Both the international weld quality system ISO 5817 and Volvo's old system were analyzed using fracture mechanics and it was found that the relation to fatigue was weak. Maybe this was not a surprise since they once were built following "good workmanship" to be able to differ one workshop quality from another. The problem however, is that the rules given in the systems are directly governing the fatigue properties, so when a designer is supposed to state the weld quality level on the drawing it is not possible to do with any confidence. It was then decided within Volvo CE to set up a new weld class system and this work was finished 2008. The rules in this new system had the goal to reflect fatigue, following a new principle as "design and weld for purpose".
A number of questions were however not solved and this project, WIQ; started 2010 to answer questions like: how is it going to be used in design ? how does it work in the weld process ? how shall inspection be made ? etc. The project adressed three parts: residual stresses, variation in weld process and inspection. Six different work packages were defined, each having a main-direction but at the same time being closely related: weld-processes, inspection, improvement methods, thermal cut sections, residual stresses and weld class systems.

3. Purpose

A new weld class system means that a new way of thinking occurs, especially regarding the co-operation between different parts of the company: design-analysis-welding-inspection. The new thing is that the new system constitutes a common language and this makes it easier to communicate what is needed and what can be done.
The purpose with the project is to make use of the principles and reduce the weight in welded components. The idea is to replace the dead weight by more pay load and so make as an example, transporting vehicles and digging machines more effective. This makes them more productive, leads to less fuel consumption at the same time as material consumption goes down and production time decreases in the workshop. Different models for total economy (from manufacturing and including service life) usually indicate big cost reductions.
The goal in the project was to reduce weight by at least 20 %.

4. How the work was carried out

The project was carried out during the years 2010-2012 with participants from 15 different companies, suppliers, universities and institutions. At Volvo CE, two doctoral students have been active at two different sites, covering one part each (weld processes & inspection) at the same time as they co-operate on the same parts. They have been attached to Chalmers and HV in Trollhättan. At KTH, two doctoral students have been involved with simulation and verification of the resdual stress part of the project. On the other companies, master thesis works and different investigations have been performed, where a lot of impressions have been taken from the project comparing the results. In project-meetings, occurring 2-3 times each year, the participants have presented their results, discussed the outcome and compared the data. These project-meetings have been circulated around the sites of the participants, and so at each occasion, a visit to the workshops or laboratories could be made. In some cases smaller meetings between the members have been made to discuss results or perform direct investigations. All results, presentations and documents have been placed on a TeamPlace, where all have access.

5. Result

The project had as a goal to implement a new weld class system in design and production of welded components, where the regulation was built to reflect fatigue. The aim was to seek answers to questions like: what are the problems ?, what is needed to do ? etc. in order to decrease the structural weight by at least 20 %.
The project was divided into 6 different work packages (WP): weld processes, inspection, improvement methods, thermal cutting, residual stresses and weld class system. These cooperated on several panes, as an example: how is the weld process affecting the weld geometry (WP1), which then is inspected in WP2 and which later could be simulated for residual stresses (WP5). Another example is that statistical theories from the academic world could be used in simulations and tests to investigate how different parameters affect the fatigue. And the other way around: how real industrial problems can influence the tools developed in the academy (example hot cracks).
Methods used in the project can in general be said to have a wide scope: the weld processes have been carried out for adaption to different requirements, inspection have used new methods (example computer based) as well as already in use (like visual) to test their capabilities using statistical methods, computer simulations of the temperatures during welding and resulting residual stresses after cooling down, FEM-simulations of mechanical stresses and fatigue, tests of fatigue in samples as well as real components, measurement of residual stresses using X-ray for verification of model results.
Some of the results are :

Overprocessing in welding, both as amount of consumables as well as position
A big potential cost reduction in operation, mostly due to decreased welding time

New weld processes adapted to requirements, old often not in right focus
Current used inspection methods not capable (ex: throat size gauges, see fig 2)
New tools for inspection of quality introduced (ex: weld toe radius)
New and improved tools for managing residual stresses and related topics
Weight reduction 20-40 % possible maintaining at least same fatigue life
New knowledge on improvement methods & thermal cutting in relation to fatigue

Figure 2 Throat size gauge

At the start of the project, the plan was to minimize the variation in the weld processes and to find inspection NDT-methods (Non-Destructive-Testing) that could solve both the old imperfections but also the new ones (like weld toe radius) defined in the new weld class system. When the work started, these parts were revaluated since new facts came in place. So the focus was shifted and this could be described as a change in the plan. The variation in welding is of course important but we found that there were more to do in adapting the weld process to the requirements: current drawings had more than 90% in the same quality level, using the same weld process regardless of the requirement needed. So it was obvious to try to develop new weld processes that could be adapted to different requirements, see fig. 3. Looking at the NDT situation, it was clear that many things were made "since they could measure it" and then sent to people around ("Push"-approach). But realizing that different people need different information and also presented in different ways, it became important to first identify who needed what and then decide action ("Pull"-approach).

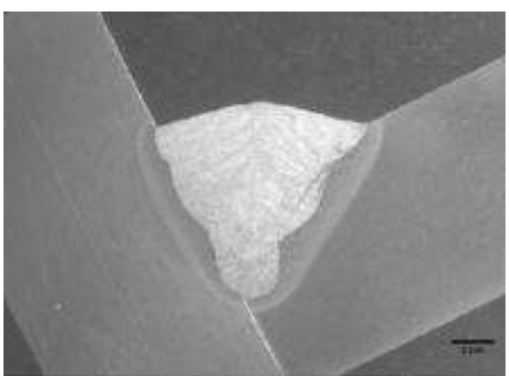

Figure 3 Fillet weld adapted to penetration

The new NDT-method developed assessing the weld toe radius was implemented quickly in production since it is an important part of the new weld quality system, see fig 4. The method was secured statistically (MSA) so that it was repeatable and reproducible. The choosed method was to avoid trying to measure the actual physical number (like R=1.5 mm), instead the radius was assessed according to in which interval the radius was (like R>1 mm), so that the weld class quality level was fulfilled.

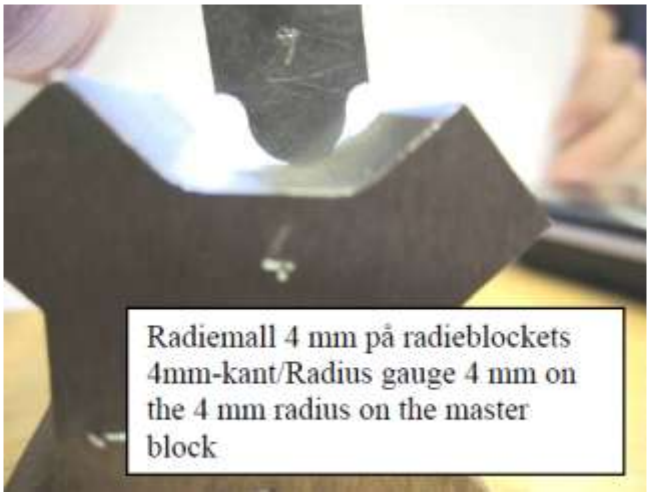

Figure 4 Radius-block, master for weld toes

Another new suggestion was also investigated and presented: when data is studied, the most common way was to look diagrams of column-type. Using control-charts (for the exact same data) instead gave a much better understanding of where problems might be. It simply presents much more things even though the under lying data is the same.
The new introduced weld class level (VE) supposed to be used where the weld root side is critical and / or whenever the weld toe side is low stressed will be introduced direct after the end of the meeting in Volvo CE. This is assumed to lead to a great influence on the drawings as more differentiated weld designations. This will further on lead to great cost reduction potential if and when the welding processes are adapted to the requirements, mostly due to decreased welding time.

5.1 Contribution to the FFI-target

As described above, the project has tried to implement a new weld class system, which can be said to have quite new approach on how to design and manufacture complex fatigue loaded welded structures. This has application on vehicles, trains, construction equipment, energy sector components etc.
The new approach can be described as whenever the design is mainly limited by fatigue loading, the important things are related to kind of load, geometry of welds, stress raisers, defects, imperfections etc. So since the weld class system describes allowed levels of imperfections and stress raisers, it should also reflect fatigue ("design for purpose" instead "of good workmanship"). Combining new "local" based analysis methods with

the new weld class system means that the design and welding can be much closer related in order to find the best solution.
For a transporting vehicle it means that using this “toolbox”, it is possible to build lighter structures and thereby increase the payload, leading to decreased specific fuel consumption. At the same time, the machine built needs less material in the structures and so also less impact on the environment.
Looking at the internal process in a company, the new approach leads to a much better understanding of the processes between people. Earlier, each part or process in the company, tended to work on his (or her) own since there was no good connection between design department and weld quality for fatigue: the design department set the weld classes according to “what we usually have done”, the welders focused on “good looking” welds and inspection followed the old standard, where rules are not well related to fatigue. In the new system relevant requirement for fatigue are set on the drawing and it then becomes interesting for the welders to accomplish that with the best or most cost effective weld process. This creates good environment for the different people within the company and a direct and productive work starts. It leads to that many new development ideas can be found and thus also an improved level of knowledge. It should also make it easier to keep the industry within Sweden since it is much more difficult to cooperate when designers and welders are in different parts of the world.
A support in the design work is to use FEM-technique in analysis, where today a very detailed and thorough result can be achieved. Many still uses the so called “nominal” method when the computed stresses are evaluated to find the fatigue life. Since this method has many in built disadvantages leading to an uncertain design with respect to fatigue, it is recommended to instead use so called “local” based methods. Here, it is possible to study stresses in any part of the weld and find a good connection to fatigue. So if companies change their way of working, a more knowledge based platform for design of welds is the result.
All the above mentioned has relevance to all welding companies, where fusion welding processes are used in moderate thicknesses, typically around 10 mm, in steel materials. However, there is reason to believe that it applies to other close related areas, materials and thicknesses.

6. Transfer and publishing

6.1 Knowledge- and Result-transfer

The results from the project will be presented on a 2-day long national conference, hosted by SSAB in Borlänge during October 2013. Invitation to this occasion will be sent out by Swedish Welding Commission (SVK) and SSAB. It means that knowledge reached will be transferred to a wide audience. A book will also be published to this conference. This means that a “toolbox” will be presented for how welded structures can be designed, analyzed, welded and inspected in order to build lighter components maintaining a good

strength for fatigue. There is also a course given annually both at SVK for the industry and at KTH for students, where the knowledge will be incorporated.
There is also a international network inside IIW (International Institute of Welding) where inspiration and knowledge can be both reached and given. Especially commission XIII (for fatigue) has several working groups close related to the topics.
Coming project related to this are Fatweld, where high strength steels are studied along with improvement methods. Another is LightStruct, where new weld processes area studied, especially plasma-hybrid.
The trend today to try to save material and environment impact implies that the question addressed in this ended project, WIQ, will be even more important in the future. So all knowledge gained will have a great impact further on.

6.2 Publications

In the project, the following publications have been made:

Master Thesis:

J. Stemp, "Fatigue assessment of an hauler bogie beam using FE analysis", Master Thesis work at Technische Universität München/Germany, TUM –MW65/07xx-TN/SA/DA, March 2012

W. Ashger, "Effect of material grade on fatigue strength and residual stresses in high strength steel welds", Master Thesis work at KTH/Sweden, April 2011.

K. Jeyabalan, "Effects of Phase Transformation on Formation of Residual Stresses in Steel Welds", Master Thesis work at KTH/Sweden, May 2012.

E. Lindgren, T. Stenberg, "Quality inspection and fatigue assessment of welded structures", Master Thesis work at KTH/Sweden, TRITA AVE 2011:02 ISSN 1651-7660, March 2011.

J. Skagersten, "Parametric Weld-design Evaluation in Crane Loader Body using Notch Stress Analysis", Master Thesis work at KTH/Sweden, TRITA-AVE 2011:28 ISSN 1651-7660, March 2011.

N. Olsson, "Optimization of Welded Joints With Respect to Fatigue", Väderstad-Verken AB.
Master Thesis work at LIU/Sweden, LIU-IEI-TEK-A--11/01055—SE, 2011.

Baradi D., "Control Strategies and Inspection Methods for Welded Part", Volvo CE AB, Master thesis work at Karlstad University/Sweden 2012.

Licentiate thesis:

B. Jonsson, "Industrial engineering systems for manufacture of welded structures exposed to fatigue", Licentiate Thesis at KTH/Sweden, TRITA AVE 2012:53 ISBN 978-91-7501-447-0, Augusti 2012.

Peigang Li, "Experimental study on cold lap formation in tandem gas metal arc welding", Licentiate Thesis at Chalmers/Sweden, ISSN 1652-8891, June 2011.

Published papers and articles:

Jonsson, B., Barsoum Z., Arezou, G.B, "Influence from weld position on fillet weld quality", Welding in the World 53 (Special issue), pp. 137-142, 2009

Hatami M K and Barsoum Z, "Fatigue assessment of cruciform joints welded in different positions", Journal of Metallurgy & Material Science, Vol. 52, No.1, pp.87-102, 2010

Barsoum Z. and Jonsson B., "Influence of weld quality on the fatigue strength in seam welds", Engineering Failure Analysis, No. 18, pp. 971-979, 2011

Barsoum Z., "Fatigue design of welded structures – some aspects of weld quality and residual stresses", Welding in the World, No. 11/12, Vol. 55, 2011

Jonsson B., Barsoum Z. and Sperle J.-O., "Weight optimization and fatigue design of a welded bogie beam structure in a construction equipment", Engineering Failure Analysis, Vol. 19, pp. 63-76, 2012

Bhatti A. A., Barsoum Z., "Classification and crack growth modeling of cold lap defects in MAG welding", Journal of Materials Science and Technology, Vol. 19, No. 2, pp. 91105, 2011

Khushid M., Barsoum Z., Mumtaz N.A., "Ultimate strength and failure modes for fillet welds in high strength steels", Journal of Materials and Design, Vol 40, pp.36-42, 2012

Barsoum Z., Samuelsson J., Jonsson B., Björkblad A., "Fatigue design of lightweight welded vehicle structures - Influence of material and production procedures", IMechE, Part B: Journal of Engineering Manufacture, Vol. 226, 10, pp.1736-1744, 2012

Bhatti A. A., Barsoum Z., "Development of efficient 3D welding simulation approach for residual stress estimation in different welded joints", Journal of Strain Analysis, Volume 47, Issue 8, pp. 539-552, 2012

Stenberg T., Lindgren E., Barsoum Z., "Development of algorithm for quality inspection of welded structures", IMechE, Part B: Journal of Engineering Manufacture, Vol. 226, 6: pp. 1033-1041, 2012

Öberg A, Hammersberg P, Svensson L-E, "Selection of Evaluation Methods for New Weld Demands: Pitfalls and Possible Solutions", In: 18th World Conference on Nondestructive Testing, Durban, 16-20 April 2012 2012.

Ericson Öberg A, Johansson M, Holm EJ, Hammersberg P, Svensson L-E (2012), "The Influence of Correct Transfer of Weld Information on Production Cost", In: The Swedish Production Symposium, Linköping Sweden, 6-8 November 2012

Ericson Öberg A., "The Subjective Judgement of Weld Quality and its Effect on Production Cost", In: Design Fabrication and Economy of Metal Structures 2013, Miskolc Hungary, April 2013.

Åstrand E., Ericson Öberg A., Jonsson B.,"Cost Affecting Factors Related to Fillet Joints", In: Design Fabrication and Economy of Metal Structures 2013, Miskolc Hungary, April 2013.

Öberg A, Hammersberg P, Svensson L-E, "Evaluation Method Designed from Information Receiver Needs and Requirements – an Enabler for Process Improvement", In: International Conference on Joining Materials, Helsingør, Denmark. 5 – 8 May 2013,

Erik Åstrand, "Weld procedures and demands for improved fatigue strength of single load carrying fillet welds", In The 9th International Trends in Welding Research Conference, Chicago, USA (2012)

Erik Åstrand. "The Ad Hoc Nature of Weld Quality and Welding Procedures for Fatigue", Accepted to the International Conference on Metal Structures: Design Fabrication and Economy of Metal Structures, Miscolc, Hungary (2013)

7. Conclusions and continued research

The main focus for this project, WIQ, was to implement a new weld class system and answer questions about coming problems and find out how to do. The overall goal was to decrease the structural weight with at least 20 % when using the system. In conclusion one can say that the system works very well and that it is quite possible to decrease the weight by 20-40% depending on the current status of the design. In a demonstrator, it was shown a weight reduction of 24%, when at the same time the tested fatigue life increased to at least twice as long as current (so both lighter and better).
Another conclusion from the project is that many things, often taken as natural, do not work at all. This applies to inspection, where often visual methods (sometimes together with some kind of gauge) are used. If these methods are tested with statistical methods, the results show lack of repeatability and reproducibility (using MSA = Measure System Analysis). Regarding the weld processes, it was discovered that almost all welds were made in the same way independent of the requirement. The focus was mainly on visual appearance instead of appropriate geometry. Here, a lot may be gained if the weld process is adapted direct to the requirements and in such a case the welder needs to overlook that the appearance is not that good. There is however a big potential in cost reduction if this approach is used, mostly due to an increased weld speed. This can be used to produce more components during available time and / or reduce the investment need when max capacity is reached. Another interesting investigation was made towards the suppliers of consumables and weld equipment. They were all asked to give advice of how to weld a certain joint in order to get the best fatigue strength. The typical advice they all gave was of the kind "use our wire XXXX" or "use our equipment YYYY". Thus, the general advice that our welding engineers get, indicates that suppliers do not have the knowledge of how to weld regarding fatigue.

Continued research within this area should be directed towards:

- Find inspection methods that fulfills tests according to MSA
- Develop better methods to measure and assess the weld toe radius
- Develop more weld processes for different requirements of fatigue and cost
- Continue developing software tools for residual stresses and connected areas
- Develop the HFMI-method within design and usage, see fig. 5
- Develop the thermal cutting standards including adaption to fatigue

Figure 5 HFMI-tool

8. Participants and contact persons

The participants in the project have been manufacturing companies, suppliers, universities and institutions:

Volvo Construction Equipment (Volvo CE), project-ledare
Volvo Lastvagnar AB
Volvo Technology
Svetskommissionen (SVK)
Cargotech (HIAB)
FORCE
SSAB
TOPONOVA
NItator I Oskarström AB
Jonsson & Paulsson Industri AB
KTH, Department of Aeronautical & Vehicle Engineering (AVE),
HV at Production Technology Centre (Trollhättan)
CHALMERS, Material and manuf. technology
Andon Automation AB

Väderstad-Verken AB

List of personal participants:

Zuheir Barsoum, KTH
Nils Stenbacka, HV
Tommy Jonasson, Jonsson & Paulsson AB
Erik Åstrand, Volvo CE
Gunnar Engblom, Cargotech
Mansoor Khurshid, KTH
Uwe Mueller, Volvo CE
Anders Ohlsson, SSAB
Peigang Li, HV
Hasse Olsson, Volvo CE
Alf Bohlin, consultant
Benny Johansson, Volvo CE
Svante Widehammar, Cargotech
Bertil Jonsson, Volvo CE
Hans Wikstrand, Volvo CE
Joachim Larsson, SSAB
Kenth Örnvall, Väderstad
Anna Öberg, Volvo CE
Stefan Rosén, Toponova
Leif Bäckman, SSAB
Tomas Tränkner, Force

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- Rapporten skrivs på både svenska och engelska (två separata).
- Max 15 sidor.
- Infoga gärna bilder och illustrationer för att öka läsförståelse.
- Om projektet har en egen slutrapport kan även denna bifogas i den elektroniska slutredovisningen.