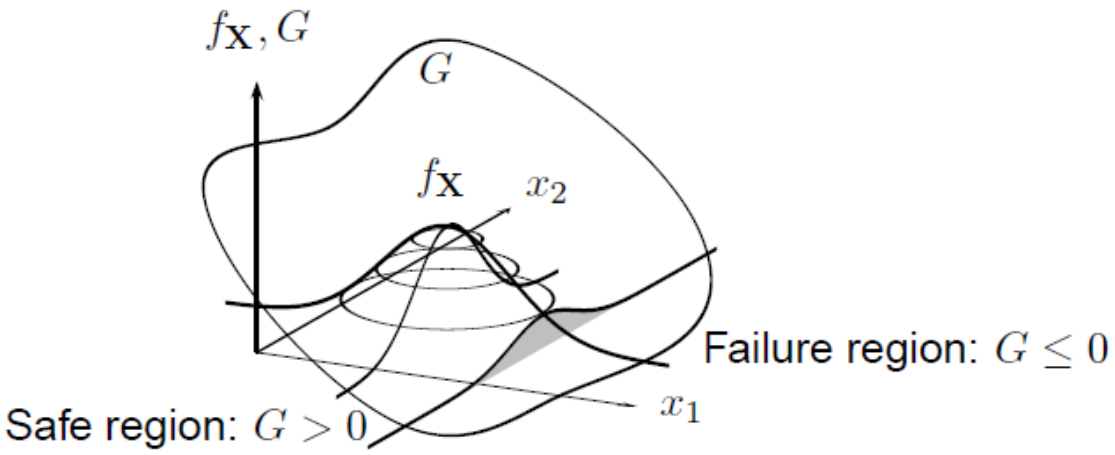
Stochastic simulation within strength calculation



A project within the **Vehicle Development** program.

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

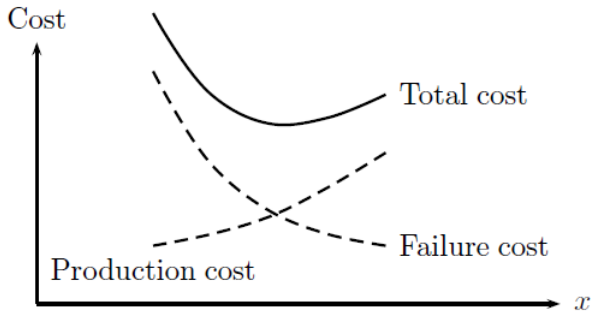
For more information: www.vinnova.se/ffi

1. Executive summary

For heavy vehicles, reliability, and thus quality, of structural components is vital. This project is aimed at developing efficient methods for computer aided prediction of the reliability of structural components with respect to strength and durability. The developed methods should be capable of including variability in important properties in simulations, a prerequisite for accurate reliability assessment of structural components. The project has been successful in meeting its aims: A method, which was found to be 80 % more efficient than the most efficient existing method for a commonly used benchmark example, has been developed. It is a necessary first step towards implementation of reliability based design processes in the vehicle industry.
Other project goals were set both by FFI and the participating parties and they were all satisfied.

2. Background

Cost and quality are key properties of a product, possibly even the two most important. One definition of quality is fitness for purpose. Load-bearing products, i.e. structural components, lose their fitness for purpose if they fail. Thus, the ability to withstand failure is a fundamental measure of quality for structural components. However, increased reliability is often associated with an increased product cost. This relation is schematically illustrated in Figur 1.



Figur 1. Schematic illustration of the relation between a design variable x and the production cost, failure cost, and total cost of a product, respectively.

Somewhat simplified, components with too low reliability will waste resources due to low utilization whereas components with too high reliability is a waste of resources due to for instance excessive use of material in production, often leading to increased operational costs as well, e.g. increased fuel consumption. Developing components with a balanced reliability enables production of components using a minimum of resources. Reliability based design optimization (RBDO) is an approach for development of structural components which aims to minimize the cost while constraining the probability

of failure. However, the computational effort of an RBDO applied to large-scale engineering problems has prohibited it from employment in industrial applications. In this project, efficient algorithms for RBDO has been developed, laying the foundation for a reliability based, and thus minimum resource consuming, design process in vehicle industry.

This project is a part of FFI. FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI will contribute to the following main goals: Reducing the environmental impact of transport, Reducing the number of killed and injured in traffic and Strengthening international competitiveness.

Within FFI, there are currently five collaboration programs. This project is a part of the Vehicle Development (VD) program which targets vehicle-related research, innovation and development activities within several areas, amongst which Development Methods pertains to this project.

3. Objective

The FFI objectives that have been deemed relevant here state that the project should (translated from Swedish):

1. Contribute to maintain the Swedish vehicle industry's competitiveness.
2. Lead to industrial technology and competence development.
3. Ensure that new knowledge is generated and implemented, and that existing knowledge is implemented in industrial applications.
4. Strengthen collaboration between the automotive industry and government agencies, universities, colleges and research institutes.
5. Promote the national competence and establish R & D which is globally competitive.

The VD program's vision is to :

- Develop and apply methods which significantly make the development process more efficient with increased quality in the entire development chain.

The stated aim is to:

- Develop verified methods which can be implemented and make product development more efficient.

In addition to these goals, the project stated the following overall goal when applying for funding:

- To develop an improved methodology for strength simulation of heavy vehicle components based on a stochastic viewpoint.

Also, a number of partial goals were stated:

1. Deeper understanding of stochastics based techniques within strength and durability simulation.
2. Robust components with the right quality.
3. A PhD within the field.

4. Project realization

The project has been conducted in cooperation between the Royal Institute of Technology (KTH) and Scania CV AB. A PhD student, Tomas Dersjö, has been responsible for the operative work. Professor Mårten Olsson at the Department of Solid Mechanics at KTH has been supervising the work and a steering committee consisting of representatives from Scania and KTH has met once per quarter to oversee the progress, in total 25 meetings.

5. Results and deliverables

The results from the project are presented in a doctoral thesis, i.e. in the research papers of which it consists. The research presented in the thesis all comprise increasingly efficient methods for computer aided prediction of the reliability of structural components with respect to strength and durability. In the final paper, a method found to be 80 % more efficient than the most efficient existing method for a commonly used benchmark example, was presented. For another, more component-like example, the computational effort of finding an optimal yet reliable design was reduced by 85 % compared to the first method developed in the project. The first presented method in turn meant significant improvements from existing approaches at the time.

5.1 Delivery to FFI-goals

The five FFI goals stated in Section 3 have all been met. The goals are somewhat general and hard to measure and thus it is hard say to what extent they have been met. However, there is no doubt that the project respond to the goals.

The VD program's vision and goal are more specific. It is the view of the project that it very well corresponds with the vision of the program. A number of research papers have been published in scientific, peer reviewed journals during the project. All of them address RBDO, i.e. methods for design of cost optimal yet reliable components, and

combined they show significant improvements compared to existing (globally) published methods. Thus, the program goal is considered fully satisfied.

The project's own overall goal is similar to that of the of the VD program and it has also been met. Regarding the partial goals, number 1) and 3) have been met and goal 2) can be expected to be the long-term effect when the PhD continue to work for Scania CV AB, applying the earned skills.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The project has rendered significant new knowledge and methods in the field of RBDO. Two papers have been published in scientific journals and two more are to be submitted. Also, the PhD student has presented the work at one national scientific conference and one international. Furthermore, the PhD student was a visiting researcher at the University of Tokyo for four weeks during his studies, extracting academic expertise and sharing results in the field of reliability. A number of visits to Japanese industrial sites were made as well, where industrial experience from development with focus on reliability was obtained.

During the project, Prof. Olsson has hired an additional PhD student working in reliability based design, and more will follow. Thus, a continuity has been established which is likely to benefit the vehicle industry in years to come.

6.2 Publications

The project has resulted in a doctoral thesis:

Dersjö, T., 2012, *Methods for reliability based design of structural components*, Doctoral thesis, TRITA HLF-0520, ISSN 1654 – 1472, ISRN KTH/HFL, Stockholm, Sweden

which can be found in full at http://kth.divaportal.org/smash/record.jsf?pid=diva2:506434. The thesis consists of an introduction and four papers. They can all be found at the web address given above; the first two only via link to the journals in which they were published and the last two in full text. The papers are

A) Dersjö, T., Olsson, M., 2011, *Reliability based design optimization using a single constraint approximation point*, Journal of Mechanical Design, 133(3):031006.
B) Dersjö, T., Olsson, M., 2012, *Efficient design of experiments for structural optimization using significance screening*, Structural and multidisciplinary optimization 45 (2), 185–196.

C) Dersjö, T., Olsson, M., 2012, *A directional surrogate model tailored for efficient reliability based design optimization*, Report HLF 2012:518, Department of Solid Mechanics, Royal Institute of Technology, SE - 100 44 Stockholm, Sweden.
D) Dersjö, T., Olsson, M., 2012, *Reliability based design optimization with experiments on demand*, Report HLF 2012:519, Department of Solid Mechanics, Royal Institute of Technology, SE - 100 44 Stockholm, Sweden.

7. Conclusions and future research

This project has been successful. More or less all of the beforehand stated goals have been satisfied. That does not mean that there is not more to be done. The work conducted in this project has foremost dealt with what was identified as the main obstacle for industrial application of reliability based design; to reduce the computer power needed. More can be done in this field, for instance when it comes to handling very small failure probabilities and correlated non-normal distributions. Moreover, there are additional challenges which should be addressed, such as model error, statistical uncertainty, and system reliability to mention a few. This is still – for a good reason - a highly active research area in which Sweden is not prominent. Thus, companies in North America, Japan, and Germany to higher extent apply an uncertainty based, or rather a uncertainty mitigation focused, development process which is likely to render them a future quality advantage if further research is not conducted.

8. Participating parties and contact persons

The participating parties in this project are Scania CV AB and the Royal Institute of Technology (KTH). The project manager is Mr Martin Edberg, Scania CV AB (martin.edberg@scania.com). He has been responsible for the economy and contact with VINNOVA. Tomas Dersjö, Scania CV AB (tomas.dersjo@scania.com), is the PhD student which has conducted the research. He has been supervised by Professor Mårten Olsson (mart@kth.se) who hold the Sverker Sjöström Chair for Reliable Structures. Questions on the technical content of the project may be directed to either Tomas or Mårten. The project has been financed in equal parts by VINNOVA and Scania CV AB.

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