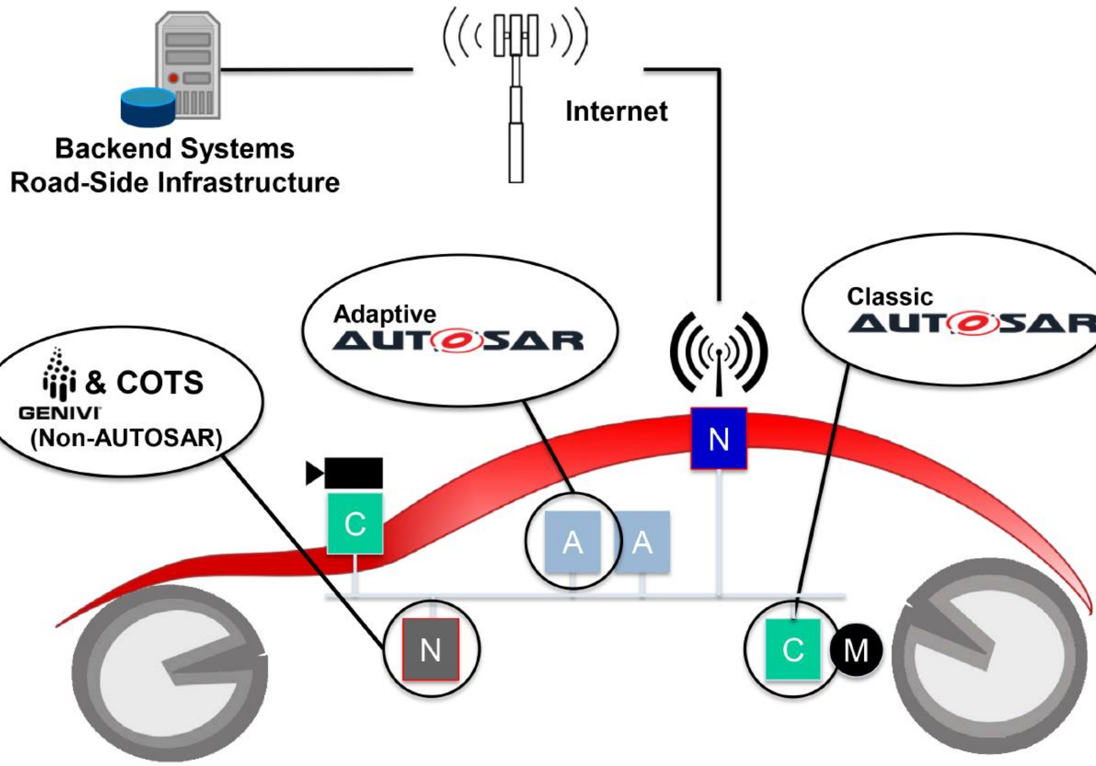
# QuaSAR@car
# Quantifying and predicting the effects of AUTOSAR meta-model changes and utilizing them in car projects

**Public report**





Project within Vinnova FFI
Author Darko Durisic
Date 2019-02-05



FFI Fordonsstrategisk Forskning och Innovation

# Content

# 1. Summary

Development of software and electronics for modern cars is based on reuse, finding commonalities and controlled variability management. To ease the reuse of components and thus optimize costs without reducing quality, AUTOSAR standard was introduced as cooperation between major car OEMs and their suppliers. Along with the adoption of the standard, new challenges are constantly identified and new concepts are introduced to the standard, constantly evolving the way in which electrical systems are developed by OEMs. To stay competitive, OEMs need to keep track of the new concepts and adapt their electrical systems quickly and cost-efficiently. Furthermore, they need to predict the impact of the changes on the existing car requirements so that they can influence their standardization. This influence is essential to keep car development costs low even in the face of growing complexity of software, its implementation and integration with electronics.

This project addresses the problem of efficient management of AUTOSAR evolution and its efficient deployment in car development projects. The problem is addressed by developing new methods and tools for:

1. Analyzing the impact of changes of AUTOSAR meta-model in terms of cost, rework and safety.
2. Automated consistency checks between electrical system requirements and AUTOSAR meta-model changes.
3. Proposing modelling solutions to the AUTOSAR consortium based on the results from car development projects.

# 2. Sammanfattning på svenska

Huvudsyftet med detta projekt var att underlätta förvaltningen av arkitektoniska uppdateringar i utvecklingen av automations-programvarusystem baserat på AUTOSAR-standarden. Vi uppnådde detta mål genom att utveckla metoder och verktyg för automatiserad utvärdering av effekten att använda nya AUTOSAR-funktioner på utvecklingsprojekt för att hjälpa systemdesigners i deras planering. Bedömningen baseras på mätningar av utvecklingen för domänspecifika metamodeller, arkitektoniska modeller och systemdesignkrav relaterade till relevanta AUTOSAR-funktioner
.
Vi utvecklade tre nya metoder och mjukvaruverktyg för automatiserad konsekvensbedömning. Den första metoden och verktyget (QTool) visar komplexitetsökningen i de arkitektoniska modellerna efter introducering av nya AUTOSAR-funktioner i systemet. Den andra metoden (MeFIA) och verktyget (ARCA) bedömer effekten att använda dessa AUTOSAR-funktioner i systemet på modelleringsverktygen som används i utvecklingsprocessen. Slutligen identifierar den tredje metoden och verktyget (SREA) en delmängd AUTOSAR-krav som påverkas av introducering av de nya funktionerna.

Vi visade i praktiken att våra metoder och verktyg möjliggör snabbare användning av nya AUTOSAR-funktioner i utvecklingsprojekten. Mer konkret visade vi att kvantitativ analys av utvecklingen av domänspecifika metamodeller, arkitektoniska modeller och systemdesignkrav relaterade till nya arkitektoniska särdrag kan vara en värdefull indikator på vilka funktioner som ska användas i systemet och hur dessa påverkar projekten. Denna kunskap kan underlätta andra industrier att utveckla stora komplexa mjukvarusystem för att hantera arkitektoniska uppdateringar i utvecklingen.

# 3. Background

The size of software in today's cars has reached 100 million lines of code and is constantly increasing. The fact that 80% of innovations in cars are related to software contributes significantly to this increase. A modern electrical system in cars is a distributed software-hardware system (a platform) with typically more than 100 Electronic Control Units (ECUs), each one responsible for a specific functionality in the car (e.g. steering, breaking, airbag activation). This growing size and complexity of software in modern cars makes quality assurance and change management (e.g. adding new functions) very difficult.

The need to retain competitive advantage entails collaborations between OEMs (Original Equipment Manufacturer, like Volvo Cars) and suppliers who deliver ECUs and their hardware and software. The involvement of multiple actors entails additional challenges towards assuring the quality during the development and integration simultaneously increasing its time and cost. To address these challenges, AUTOSAR standard emerged in 2003 as a joint partnership of car manufacturers and suppliers in order to facilitate efficient collaboration between OEMs and suppliers and to enable sharing development costs between different actors.

# 4. Purpose, research questions and method

## 4.1 Purpose and research questions

The main purpose of this project was to assure the quality of electrical system in cars and to reduce its development lead-time when adopting new releases of the AUTOSAR standard. As new AUTOSAR releases usually bring a set of new automotive architectural features into the electrical system, we defined our main research question as follows:

**RQ: How to automatically assess the impact of using new architectural features in the system on automotive software development projects?**

Using new architectural features in the system causes the evolution of domain-specific meta-models, architectural models and system design requirements. The evolution of these three MDE artifacts, however, has significant impact on the development projects. The evolution of meta-models requires updates of the used modeling tools and possibly existing models. The evolution of architectural models usually requires verification and validation of the entire system. The evolution of design requirements requires detailed inspection of the requirement specifications for the correct use of new features in the models. Therefore in order to be able to assess the impact of using new architectural features on the development projects, we needed to analyze the evolution of architectural meta-models, models and design requirements, each representing one direction in our study.

In order to address our main research question, we divided it into fourteen smaller research questions, each addressed in one of our eight papers (see publication list in Section 7.2). These questions, including a short description of our contributions in each paper, are presented in the table below.

| No. | Research question | Contribution/finding | Paper |
|---|---|---|---|
| RQ1 | How can the complexity increase of architectural models and their components be monitored during the evolution of large software systems? | Two measures are needed to monitor the complexity evolution of automotive architectural models when new architectural features are added to the system - the measures of architectural complexity and coupling. *QTool* can be used for combined analysis of results of these two measures. | Paper A |
| RQ2 | What are the consequences of UML based loose meta-modeling in the automotive domain? | The main consequence is that not all semantics can be conveyed between meta-modeling layers by means of modeling, e.g., which defined stereotypes are applicable to classes and which to associations. In practice, this is solved by the modeling tools by providing means to specify additional semantics. | Paper B |
| RQ3 | What are the drawbacks of approaches for assuring strictness of the AUTOSAR meta-model? | The main problem with approaches assuring strictness is the lack of tool support and their relatively short and narrow use in industry. | Paper B |
| RQ4 | What are the practical meta-modeling concerns of the automotive modeling practitioners? | One of the major practical concern of the automotive modeling practitioners is the impact of evolution of domain-specific meta-models on other artifacts in the development process. | Paper B |
| RQ5 | How can the evolution of domain-specific meta-models be measured in order to accurately reflect the impact of meta-model changes on the modeling tools used by different actors in the development process? | A simple measure of meta-model change (*NoC*) can be used as a preliminary indicator of impact of new domain-specific meta-model versions on the used modeling tools. | Paper C |
| RQ6 | What types of changes can be distinguished between different versions of the AUTOSAR meta-model? | Data model that captures all relevant meta-model changes for analyzing the evolution of the AUTOSAR meta-model. | Paper C |

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|---|---|---|---|
| RQ7 | How can the evolution of the AUTOSAR meta-model be quantified? | *NoC* measure based on our data model for quantifying the evolution of the AUTOSAR meta-model. | Paper C |
| RQ8 | How accurately can quantitative analysis of the AUTOSAR meta-model changes be used for predicting its impact on the AUTOSAR tools? | Statistically significant positive Spearman's correlation of 0.69 between the results of *NoC* and the actual effort needed to update the AUTOSAR based modeling tools. | Paper C |
| RQ9 | What is the level of applicability of the measures of domain specific meta-model evolution and the underlying data-model defined in (Durisic et al., 2014) for monitoring the evolution of Modelica/UML meta-models? | The *NoC* measure and the underlying data-model are applicable for measuring the evolution of two additional meta-models of Modelica and UML. | Paper D |
| RQ10 | How to assess the impact of different architectural features on the used domain-specific meta-models? | The *MeFIA* method can be used for assessing the impact of new architectural features on domain-specific meta-models. | Paper E |
| RQ11 | How to identify the optimum set of features to be adopted based on the assessed impact? | The *MeFIA* method can be used for identifying optimal sets of new architectural features to be used in the development projects. | Paper E |
| RQ12 | How to support modeling practitioners in analyzing changes between different versions of domain-specific meta-model related to different architectural features? | The *ARCA* tool realizing the *MeFIA* method can be used to support automotive modeling practitioners in deciding which new AUTOSAR features to use in the development projects. | Paper F |
| RQ13 | How can we assure efficient adoption of new releases of standards in the development of large software systems by analyzing the evolution of standardized requirements? | The *SREA* tool can be used to support organizations in understanding which parts of the system will be mostly affected by the changes in the system design requirements. | Paper G |
| RQ14 | How strong is the relation between the evolution of meta-modeling syntax and meta-modeling semantics? | Statistically significant positive Spearman's correlation of 0.63 between the results of the *NoC* measure (for meta-modeling syntax) and the *Number of changed requirements* (for meta-modeling semantics). | Paper H |

## 4.2 Research method

The research methodology used in this thesis mainly consists of a series of case studies, which aim to increase understanding of meta-models, models and system requirements, and validate our methods used for monitoring the evolution of certain properties of these three artifacts. Using only one research method, however, does not usually suffice for the combined work of practitioners and researchers for solving industrial problems. Therefore, our methods are developed following the methodology of constructive research, which relies on the results of our case studies. As all of our methods were based on the use of software measurement, we used the methodology of the GQM (Goal-Question-Metric) approach as part of the constructive studies for developing the actual measures.

In order to address our research questions, we conducted eight studies, each described in one of the Papers A-H (see Section 7.2). Three studies were conducted using the case study method, four studies were conducted using constructive research, which included additional case studies, and one study was a tool presentation.

# 5. Objective

This main objective of the project was to enable efficient management of AUTOSAR evolution and its efficient deployment in car development projects. In the short term the project was expected to contribute to significant lowering of AUTOSAR adaptation due to automated change impact analyses. In the long run the project was expected to enable faster and cheaper innovation cycles in car projects, increased reuse and delivers methods and tools to be used in the development of the car projects and also AUTOSAR standard through Volvo's representatives. Both short term and long term objectives of this project have been successfully met.

# 6. Results and deliverables

We developed three new methods and software tools for automated impact assessment of new AUTOSAR releases. The first method and the tool (*QTool*) show the complexity increase in the architectural models after adding a set of new AUTOSAR features to the system. The second method (*MeFIA*) and the tool (*ARCA*) assess the impact of using these AUTOSAR features in the system on the used modeling tools. Finally, the third method and the tool (SREA) identify a subset of AUTOSAR requirements that are affected by the use of the new features.

All project results are directly implemented at Volvo Cars and potentially other AUTOSAR partners (e.g., AB Volvo) by means of incorporating these tools into the company's change management process.

We aimed to address the following FFI-program objectives in our project:

- ***contribute towards a vehicle industry in Sweden that continues to be competitive***

  The methods and tools developed in this project provide OEMs with the ability to react quickly to changes, predict their impact thus keeping the development costs low without jeopardizing release schedules or vehicle quality.

- ***undertake development initiatives of relevance to industry***

  Designing electrical systems in cars based on the AUTOSAR meta-model is necessary due to the prevalence of the AUTOSAR standard on the automotive market. Therefore, the results of this project are of high relevance to the industry.

- ***lead to industrial technology and competence development***

  Our dissemination of project results in different industrial and academic venues led to an increase competence in architectural modeling in the automotive domain and

AUTOSAR based development of automotive software systems. Additionally, the project resulted in a book chapter on AUTOSAR which is quite useful for newcomers in the automotive domain.

- ***contribute towards secure employment, growth and stronger R&D operations***

  This research project increased the efficiency of adopting new AUTOSAR releases and concepts which improves the competitiveness of vehicle industry on the market. This contributes to secure employment and growths as AUTOSAR solutions result in more long-term platforms thus more sustainable development of the automotive sector.

- ***support environments for innovation and collaboration***

  This research project is done in collaboration with *Software Center* at Chalmers/University of Gothenburg, which is a collaborative research environment with a number of partners from industry and academia.

- ***strive to ensure that new knowledge is developed and implemented, and that existing knowledge is implemented in industrial applications***

  The project results are validated through in-kind projects at the development site at Volvo Cars (electrical systems). All tools developed in this project are used in production project at Volvo Cars and other AUTOSAR partners (e.g., AB Volvo).

- ***reinforce collaboration between the vehicle industry on the one hand and the Swedish Road Administration, universities and research institutes on the other***

  The contribution to this target was focused on universities and research institutes, as explained above. Swedish Road Administration, despite being planned to be indirectly involved, was not part or the project (minor deviation).

- ***strive to secure national supplies of competence and to establish R&D with competitive strength on an international level***

  AUTOSAR is an international standard and its implementation has influence on the international level. Therefore the results from this project are relevant for all OEMs who develop projects based on the AUTOSAR compliant electrical system.

# 7. Dissemination and publications

## 7.1 Dissemination

| How are the project results planned to be used and disseminated? | Mark with X | Comment |
|---|---|---|
| Increase knowledge in the field | X | Our dissemination of the project results in different industrial (company presentations, workshops, Software Center) and academic (conferences) venues led to an increase awareness of architectural modeling in the automotive domain and the role of AUTOSAR standard in the development of automotive software systems.<br><br>Additionally, the project resulted in a book chapter on AUTOSAR which is quite useful for newcomers in the automotive domain. |

| | | |
|---|---|---|
| Be passed on to other advanced technological development projects | | |
| Be passed on to product development projects | X | All tools developed in this project are used in production project at Volvo Cars and have also been delivered to Volvo AB and several other AUTOSAR partners. |
| Introduced on the market | | |
| Used in investigations / regulatory / licensing / political decisions | | |

## 7.2 Publications

This project resulted in the following doctorate thesis: “Measuring the Evolution of Meta-models, Models and Design Requirements to Facilitate Architectural Updates in Large Software Systems”, ISBN: 978-91-982237-5-0.

The theses was based on the following publications:

A. D. Durisic, M. Nilsson, M. Staron and J. Hansson, "Measuring the Impact of Changes to the Complexity and Coupling Properties of Automotive Software Systems", Journal of Systems and Software (JSS), vol. 86, no. 5, pp. 275-1293, 2013

B. D. Durisic, M. Staron, M. Tichy, J. Hansson, "Addressing the Need for Strict Meta-Modeling in Practice - A Case Study of AUTOSAR", Proceedings of the 4th International Conference on Model-Driven Engineering and Software Development (MODELSWARD), pp. 317-322, 2016

C. D. Durisic, M. Staron, M. Tichy, J. Hansson, "Assessing the Impact of Meta-Model Evolution - A Measure and Its Automotive Application", Journal of Software and Systems Modeling (SoSyM), pp. 1-27, 2017

D. M. Jimenez, D. Durisic, M. Staron, "Measuring the Evolution of Meta-Models - A Case Study of Modelica and UML Meta-Models", Proceedings of the 5th International Conference on Model-Driven Engineering and Software Development (MODELSWARD), 2017

E. D. Durisic, M. Staron, M. Tichy, "Identifying Optimal Sets of Standardized Architectural Features - A Method and its Automotive Application", Proceedings of the 11th International Conference on Quality of Software Architectures (QoSA), pp. 103-112, 2015

F. D. Durisic, M. Staron, M. Tichy, J. Hansson, "ARCA – Automated Analysis of AUTOSAR Meta-Model Changes", Proceedings of the 7th International Workshop on Modeling in Software Engineering (MiSE), pp. 30-35, 2015

G. C. Motta, D. Durisic, M. Staron, "Should We Adopt a New Version of a Standard? - A Method and its Evaluation on AUTOSAR", Proceedings of the International Conference on Product-Focused Software Process Improvement (PROFES), pp. 127-143, 2016

H. D. Durisic, C. Motta, M. Staron, M. Tichy, "Co-Evolution of Meta-Modeling Syntax and Semantics in Architectural Domain-Speci_c Modeling Environments - A Case Study of

AUTOSAR", Proceedings of the 20th International Conference on Model Driven Engineering Languages and Systems (MODELS), 2017

Additional publications done within the scope of this project:

I. D. Durisic, M. Staron and M. Nilsson, "Measuring the Size of Changes in Automotive Software Systems and their Impact on Product Quality", Proceedings of the 12th International Conference on Product Focused Software Development and Process Improvement (PROFES), pp. 10-13, 2011
J. D. Durisic, M. Staron, M. Tichy, J. Hansson, "Evolution of Long-Term Industrial Meta-Models - An Automotive Case Study of AUTOSAR", Proceedings of the 40th EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA), pp. 141-148, 2014
K. D. Durisic, M. Staron, M. Tichy, J. Hansson, "Quantifying Long-Term Evolution of Industrial Meta-Models - A Case Study", Proceedings of the International Conference on Software Process and Product Measurement (MENSURA), pp. 104-113, 2014
L. D. Durisic, "AUTOSAR", Chapter in Automotive Software Architectures book, Springer, 2017

# 8. Conclusions and future research

The main contribution of this thesis are three methods (and software tools) that can be used for automated impact assessment of using new architectural features on the development projects. We showed that using these methods and combining their results in the development process is able to accelerate the work of system designers responsible for planning architectural updates in the development of automotive software systems based on the AUTOSAR standard. This, in turn, enables faster and cheaper innovation cycles in the car development projects.

The results presented in this theses provide opportunities for further research in the area of meta-model and system requirements evolution. Related to the evolution of meta-models, one direction could be to classify meta-model changes into categories according to their impact on different segments of the modeling tools (e.g., graphical user interface, tool importers or underlying data-base) and identify the ones that require most rework in the tools. Another direction could be to analyze the relation between different features based on their impact on the same parts of the meta-model. The results of such a study can be used to group similar features that should be used together in the development project.

Finally related to the evolution of system requirements, one direction could be to include natural language processing (NLP) techniques in the analysis performed by the *SREA* tool. This approach has a potential to additionally increase the speed of analyzing changes in the requirements specifications related to the use of new architectural features in the system, by filtering out syntactically changed requirements that have no semantic impact.

# 9. Participating parties and contact persons

In this project we combined the competence from the Software Engineering division and Software Center at Chalmers/University of Gothenburg and Volvo Cars (groups: System architecture, ECU architecture, AUTOSAR team).

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| Volvo Cars<br><br>Dr. Darko Durisic<br>darko.durisic@volvocars.com<br>+46 72-371 69 60 | University of Gothenburg<br><br>Prof. Miroslaw Staron<br>miroslaw.staron@gu.se<br>+46 31-772 10 81 |