Institution: Aberystwyth University

Unit of Assessment: 11

Title of case study: Automated Design Analysis and Generation of Diagnostics

1. Summary of the impact

Automotive design analysis software based on qualitative reasoning research in the Advanced Reasoning Group at Aberystwyth is deployed at more than 200 automotive and aeronautic OEMs and Tier 1 suppliers world-wide. The software necessitates companies changing their process for performing design analysis, and companies are willing to do this because of the attendant benefits.

The major benefits of use of the software are early feedback on potential problems with the design of automotive systems, and improved safety of automotive designs. Related benefits are improved product time to market, and cost savings. A representative example of production savings of $2.5 million has been given for use of the software on a single product design, as well as Ford Motor Company's estimate of $20M per year saved in just their company.

2. Underpinning research

The Advanced Reasoning Group at Aberystwyth have been a leader in Qualitative Reasoning Research for more than 15 years. For a good deal of that period, it was funded to coordinate qualitative reasoning in Europe as lead node of the European network on Model-based and Qualitative Reasoning (MONET - 1995-2001; MONET2 - 2001-2006). During this time, one significant strand of its research was aimed at automating design analysis and at producing diagnostics for automotive systems. The design analysis automation research was funded by EPSRC and the EC, and carried out in collaboration with companies including Ford, Jaguar, the Motor Industry Research Association, Daimler-Benz, Fiat, Volvo. Research in this area has continued during the REF period with funding from the Technology Strategy Board, BAE Systems, Flight Refuelling and Sumitomo Electrical Wiring Systems.

The research resulted in several key developments between 1995 and 2005. Aberystwyth developed novel techniques for qualitative reasoning of electrical systems [3.1,3.2], and for deciding on the effects of component failure in a system and abstracting the results to an appropriate level for presentation to users [3.3]. The use of qualitative reasoning to decide current flow in electrical networks [3.1] coupled with a higher level state-based component representation [3.2] was pioneered in the group, and proved effective for simulation of automotive electrical circuits. Such representations were easier to build from reusable libraries than the equivalent numerical simulation, and covered a wider range of possibilities, including failure situations. The use of functional labels to interpret system level states and provide natural language analysis reports [3.3] also originated in the group, and this innovation made it possible to produce focused results in language appropriate for engineers.

In addition, because the qualitative models could be adapted for use in a wider range of tasks than was possible with numerical simulation, methods could be developed for combining these features together in order to achieve different kinds of task-based reasoning, and the group produced further novel design analysis tools that were of commercial interest [3.4,3.5,3.6].

The ease of model building for the engineers, the wide applicability of the models constructed, and the usefulness of the results achieved, were attractive to automotive companies, and Ford Motor Company funded the initial commercial development of tools based on the research prototypes built by the group on EPSRC grants.

Research in this area has continued at Aberystwyth since the formation of the spin-out company, FirstEarth, continuing to improve the modelling techniques, and to develop novel diagnostic and design tools using these techniques, specifically widening the application area from electrical systems to mixed domain systems, and pioneering new kinds of analysis (diagnosability and automated generation of on-line diagnostics). One example of this on-going work is given in [3.6].

Key Researchers:
Mark Lee, Professor
Chris Price, Professor
Neal Snooke, Lecturer (01/09/1997)

3. References to the research

[3.1] M. H. Lee. Qualitative circuit models in failure analysis reasoning. *Artificial Intelligence* 111 (1-2), pp239-276, 1999. DOI: 10.1016/S0004-3702(99)00032-6

[3.2] N. A. Snooke, Simulating electrical devices with complex behaviour, *AI Communications* 12 (1,2) pp45-58, 1999.

[3.3] C. J. Price, Function-directed electrical design analysis, *Artificial Intelligence in Engineering* 12 (4) pp445-456, 1998. DOI: 10.1016/S0954-1810(97)10013-9

[3.4] C. J. Price, N. A. Snooke, S. D. Lewis. A layered approach to automated electrical safety analysis in automotive environments. *Computers in Industry* 57, pp451-461, 2006. DOI: 10.1016/j.compind.2006.02.001

[3.5] C. J. Price and N. S. Taylor, Automated Multiple Failure FMEA, *Reliability Engineering and System Safety* 76(1), pp1-10, 2002. DOI: 10.1016/S0951-8320(01)00136-3

[3.6] N. Snooke, C. J. Price. Automated FMEA-based diagnostic symptom generation. *Advanced Engineering Informatics* 26(4), pp870-888, 2012. DOI: 10.1016/j.aei.2012.07.001 REF2 submitted.

Details of grants

[3.7] Grant: An Automated FMEA Assistant. Jan 1993 - December 1995, £217K from EPSRC and £21K from Ford Motor Company.

[3.8} Grant: AQUAVIT: Advancing Qualitative Analysis for Verification, Interaction analysis and Testing. April 1996 - March 1999, £215K from EPSRC(CDP) Grant GR/L20542 and £55K from Ford Motor Company.

[3.9] Direct funding from Ford Motor Company to develop AutoSteve. Oct 1995-March 1997. £203K.

[3.10] Grant: VMBD: Vehicle Model Based Diagnosis. £144K from European Commission DG XIII (total project size £4M) .

[3.11] Grant: Whole Vehicle, Whole Lifecycle Electrical Design Analysis. January 2000 - May 2003. £245K from EPSRC (Foresight Vehicle) Grant GR/N06052 and £219K from Ford Motor Company.

[3.12] Grant: ASTRAEA: Safety Cases for Unmanned Aerial Vehicles. (£218K). This was a wide ranging project led by Technology Strategy Board with a total value of £32M. Aberystwyth

received funding in automated detection of on-board problems using qualitative models.

4. Details of the impact

Automotive design analysis tools based on qualitative reasoning research at Aberystwyth are deployed at more than 200 automotive and aeronautic OEMs and Tier 1 suppliers world-wide [5.1]. In order to use the tools, engineers in the companies need to change their design processes, but this is seen as being worthwhile, because of the improved safety and the potential for cost savings that results.

Safety is improved, because safety design analysis can be carried out early in the design process and then repeated painlessly as the design evolves [3.4,3.5]. Cost savings result both from the reduced engineer effort needed to do the safety analysis, and from the fact that the analysis can been carried out early in the design process - fixing design problems early is much cheaper than fixing them late in the design process.

The qualitative reasoning based automated FMEA research described in the papers in section 3 led to the first ever commercial automated FMEA tool, called AutoSteve, developed by Aberystwyth Computer Science in collaboration with Ford Motor Company. This resulted in a spin-out company, FirstEarth, that supported and further developed AutoSteve, marketing and selling it to other automotive companies. FirstEarth was well supported by the Department over a five year period (1998-2003), and further results of our research were embodied in its design analysis tools. Researchers, academic members of staff, graduate and undergraduate students were all seconded to the company at some point. At its height, the company employed 12 staff, and of those, nine had been trained by the Department. Of those nine, six chose to work for Mentor Graphics when it bought FirstEarth in 2003, and four of those (all originally RAs on related research projects) are still key technical staff for Mentor Graphics in their Newbury research and development centre [5.1].

FirstEarth Limited and Aberystwyth University developed further commercial automated design analysis tools based on the continuing research at Aberystwyth. These include automated sneak circuit analysis, fusing strategy design analysis, and simple design verification. The underlying qualitative reasoning meant that all these tools were able to work on a single library of system models built by automotive engineers, and that useful analysis could be carried out much earlier in the automotive design lifecycle than had previously been possible. A language for describing the function of systems that had been developed as part of the research, along with ways of using that language to interpret system behaviour, and this meant that the tools could generate consistent reports in the kind of language used by engineers and managers - another significant advantage over previous tools.

When Mentor Graphics took over FirstEarth Limited, they incorporated the tools into their "Capital" harness design toolkit, and renamed AutoSteve as part of the toolkit. They have split AutoSteve into four tools that support Capital Harness Design, all built on the Aberystwyth research described above [5.2]. The subtext after each tool name is the description from their website of what that tool does for the engineer:

- Capital SimCertify: Bullet proof design using FMEA
- Capital SimProve: Eliminate sneak faults
- Capital SimStress: Size components for worst-case configurations
- Capital SimTransient: Validate transient behaviour

In order to estimate the reach of the impact of this research, in 2012 we asked the Integrated Electrical Systems Division (IESD) of Mentor Graphics about the usage of this technology over the past few years. They informed us that Mentor Graphics presently has design tools based on technology developed at Aberystwyth installed at over 200 vehicle producers and Tier 1 suppliers. These tools are having a significant effect on improving vehicle safety and on the efficient production of vehicle designs. Potential design problems are identified early.

The tools are also saving significant design costs. The rapid automated safety analysis of designs means that many more design options can be explored cheaply. A recent example of this is provided by one of the world's largest producer of automotive harnesses. In 2009, the company used the tools to identify how to save 50 cents per harness produced. When you are producing 5 million harnesses, that gives savings of $2.5 million for a single product.

In 1999, the Ford team working with FirstEarth and Aberystwyth University on AutoSteve was awarded a Ford Europe Technology prize for the impact of AutoSteve. The business case produced by Ford in submission for the prize estimated that AutoSteve was then saving Ford around $20M per year, but that the key benefit was the improved analysis of design safety [5.3].

The supporting impact letter from Mentor Graphics says "Mentor Graphics presently has design tools which include technology developed at Aberystwyth deployed at more than 200 vehicle producers and Tier 1 suppliers.", and highlights both "improved design quality" and "usage can also result in significant cost savings". Given increases in costs since Ford did their study in 1999, and the wide deployment of these tools, we conclude that the overall economic impact is very significant indeed.

5. Sources to corroborate the impact

[5.1] Confirmation of the present state and usage of the tools can be obtained from the Product Line Director at Mentor Graphics Inc.

[5.2] Mentor's web site also has details of Capital Harness Software (http://www.mentor.com/products/electrical-design-software/capital/) and of the Capital design analysis products that were originally AutoSteve (http://www.mentor.com/products/electrical-design-software/capital/additional-automation/electrical-analysis).

[5.3] Details of the Ford Technology Prize for the AutoSteve work are given on page 32 of an article in AI Magazine: P. Struss and C. J. Price, Model-based systems in the automotive industry, AI Magazine special issue on Qualitative Reasoning, pp17-34, vol. 24(4), Winter 2003.