

Impact case study (REF3b)

Institution: University of York
Unit of Assessment: 11, Computer Science and Informatics
Title of case study: Automotive Real-Time Operating Systems (RTA-OSEK & RTA-OS) [REDACTED VERSION]
1. Summary of the impact (indicative maximum 100 words)

Impact:

The underpinning research was exploited to design an exceptionally efficient Real-Time Operating System (RTOS), used in automotive Electronic Control Units (ECUs), and its associated schedulability analysis tools. Since 2008, the RTOS has been deployed in 50 to 55 million new ECUs each year. The RTOS has been standardised upon (used by default in all ECUs) by [TEXT REMOVED FOR PUBLICATION]. ([TEXT REMOVED FOR PUBLICATION] in terms of world-wide automotive powertrain systems suppliers. [TEXT REMOVED FOR PUBLICATION] all rank in the top [TEXT REMOVED FOR PUBLICATION] world-wide for chassis electronics). The RTOS is used in cars produced by [TEXT REMOVED FOR PUBLICATION] as well as many others. Revenues from the RTOS exceed [TEXT REMOVED FOR PUBLICATION] per year.

2. Underpinning research (indicative maximum 500 words)
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Context:

In real-time embedded systems, such as the ECUs used in vehicles, system functionality is decomposed into multiple software tasks running on a microprocessor. The system requirements place time constraints on these tasks. Hence a task may be required to execute every 10 milliseconds, read and process data from sensors, and output its results within a specific time constraint or deadline. When there are multiple tasks with different periods and deadlines running on the same microprocessor, an RTOS is needed to schedule when each task should execute. It is essential that all of the tasks are guaranteed to meet their deadlines during operation; otherwise the system may suffer from intermittent timing faults that compromise its functionality and reliability.

Given the complex behaviour of these systems, it is impossible to obtain a 100% guarantee that tasks will always meet their deadlines via testing. Instead, a rigorous scientific and systematic solution to this problem is *schedulability analysis*; a set of techniques used to determine off-line if each task can be guaranteed to meet its deadline under a specific scheduling policy. Schedulability analysis is used to compute the *worst-case response time*, the longest time that can elapse from a task being released to it outputting its results and completing execution. If this is less than the deadline, then the task can be guaranteed to always meet its time constraints.

Underpinning research:

The seminal research that underpins the impact is a set of schedulability analysis techniques [1], [2], [3], [4], and [5] for fixed priority pre-emptive scheduling, originally called *Deadline Monotonic Schedulability Analysis* but now widely referred to as *Response Time Analysis*, developed by the Real-Time Systems Research Group (RTSRG) at the University of York.

The schedulability analysis derived is applicable to fixed priority scheduling, and a task model that accurately accounts for the detailed timing behaviours of tasks in automotive systems. These timing behaviours include: tasks that are invoked sporadically (i.e. with minimum inter-arrival times, but not necessarily strictly periodically in time – for example tasks that are triggered off of a crank angle sensor measuring engine rotation); tasks with deadlines that are less than their periods and prior to completion [1], [2] – accounting for tasks that need to make a response prior to their next invocation to avoid buffer overruns, and to carry out further computations after a response has been made, in preparation for the next cycle; tasks with offset release times [4] – used as a means of avoiding peak load in short time intervals; tasks with jittered released times [5] – that are triggered by the arrival of messages that can take a variable amount of time to be transmitted, and tasks that share resources [1], [2] – such as data structures and peripheral devices used for communication. The analysis also accounts for the overheads of a well-designed RTOS [3].

The underpinning research therefore introduced for the first time, schedulability analysis that could be applied in practice to commercial real-time systems, providing a rigorous approach to obtaining timing correctness. This was recognised in the EPSRC International Review of Computer Science undertaken in 2002:

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The techniques developed built upon other important research contributions such as the Stack Resource Policy / Priority Ceiling Protocol for resource locking; however, without the work of the researchers in the RTSRG, the impact would not have been possible due to the fact that the underlying models used by prior schedulability analysis were too limited to be used in practice.

The research was carried out by five members of the RTSRG, Computer Science Department, University of York; Neil Audsley, Alan Burns, Mike Richardson, Ken Tindell, and Andy Wellings. Neil Audsley, Mike Richardson and Ken Tindell were Research Associates, and Alan Burns and Andy Wellings were members of the academic staff during this time. All of the underpinning research was published after 1st Jan 1993.

Robert Davis was also a Research Associate in the RTSRG from 1992-1995, working with Neil Audsley, Alan Burns, Ken Tindell and Andy Wellings.

Alan Burns, Andy Wellings, and Neil Audsley have remained members of the RTSRG to the present day (Sept. 2013). Ken Tindell left the RTSRG on 30/09/1994, after the underpinning research was completed. Mike Richardson left the RTSRG on 23/10/1993 after completing his contribution to the underpinning research [1]. Robert Davis left the RTSRG in 1995 and re-joined in 2004.

3. References to the research (indicative maximum of six references)

[1] N.C. Audsley, A. Burns, M. Richardson, K.W. Tindell, A.J. Wellings, "Applying New Scheduling Theory to Static Priority Pre-emptive Scheduling". Software Engineering Journal, Volume 8, Issue 5, pages 284-292, 1993. ISSN :0268-6961 (Available on request)

[2] N.C. Audsley, A. Burns, A.J. Wellings, "Deadline Monotonic Scheduling: Theory and Application". Control Engineering Practice, Volume 1, No. 1, pages 71-78, 1993. DOI:10.1016/0967-0661(93)92105-D

[3] A. Burns, A. J. Wellings, "Engineering a Hard Real-Time System: From Theory to Practice" Software Practice and Experience, Volume 25, Issue 7, pages 705-726, July 1995. DOI: 10.1002/spe.4380250702.

[4] N.C. Audsley, K.W. Tindell, A. Burns, "The End Of The Line For Static Cyclic Scheduling?" In proceedings, 5th Euromicro Workshop on Real-Time Systems, pages 36-41, June 1993. DOI: 10.1109/EMWRT.1993.639042

[5] K.W. Tindell, A. Burns, A.J. Wellings, "An extendible approach for analyzing fixed priority hard real-time tasks". Real-Time Systems, Volume 6, Issue 2, pages 133-151, 1994. DOI: 10.1007/BF01088593.

Number of citations to the key papers: Google Scholar 29th August 2013: [1] – 945, [2] – 91, [3] – 46, [4] - 127 [5] – 511, Scopus 29th August 2013: : [1] – not indexed, [2] – 31, [3] – 13, [4] – not indexed, [5] – 182). References [1], [2], and [5] best indicate the quality of the underpinning research.

The research was undertaken on the EPSRC grant GR/H39611 Real-Time Systems Engineering – PI Prof. Andy Wellings: July 1992 – Dec 1995, funding £244,920.

4. Details of the impact (indicative maximum 750 words)

Impact:

The underpinning research was exploited in the design of an RTOS, used in automotive ECUs, and its associated schedulability analysis tools. The research was initially exploited by a start-up company founded by University of York researchers, which was subsequently bought by ETAS (www.etas.com/en/). ETAS currently sell two versions of the RTOS, RTA-OSEK and RTA-OS compliant with the OSEK (*Offene Systeme und deren Schnittstellen für die Elektronik in Kraftfahrzeugen*; in English: "Open Systems and their Interfaces for the Electronics in Motor Vehicles") and AUTOSAR (AUTomotive Open System ARchitecture) operating system standards respectively.

The RTOS is currently available for more than 25 different ECU microcontrollers [6] including: Renesas: V850E, SH2, SH2A, H8S, H8SX, M16C; Xilinx Microblaze, PPC405 Core; Texas Instruments TMS470P, TMS570P; Infineon Tricore TC17x6, C166, XC2000; Freescale Star12,

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MPC555, MPC55xx, S12X, MPC56x, HC12X16, HC08, HCS12; Fujitsu 16LX; Analog Devices Blackfin, STMicroelectronics ST30, ST7, ST10.

Since 2008, the RTOS has been deployed in 50 to 55 million new ECUs each year. ETAS customers for the RTOS cover a wide range of application areas within Automotive Electronics: [TEXT REMOVED FOR PUBLICATION]. Each of these customers supplies different families of ECUs incorporating the RTOS.

The RTOS has been standardised upon (used by default in all ECUs) by [TEXT REMOVED FOR PUBLICATION]. ([TEXT REMOVED FOR PUBLICATION] in terms of world-wide automotive powertrain systems suppliers. [TEXT REMOVED FOR PUBLICATION] all rank in the top [TEXT REMOVED FOR PUBLICATION] world-wide for chassis electronics).

The RTOS is used in vehicles produced by [TEXT REMOVED FOR PUBLICATION] and many others.

Revenues from the RTOS exceeds [TEXT REMOVED FOR PUBLICATION] per year.

Corroboration of all of the facts presented above about ETAS and its products and customers etc. can be obtained from [7].

Route to Impact:

Above we detailed specific exploitation of the technology and impact and during the REF period. Below we detail the evidential link between the underpinning research and that impact.

In 1997, Robert Davis and Ken Tindell (both previously members of the RTSRG) co-founded a company called Northern Real-Time Applications (NRTA) Ltd., with the aim of developing an RTOS and schedulability analysis tools specifically tailored to automotive applications that use low cost microcontrollers. In doing so, they utilised the underpinning research that they had been involved in and heavily exposed to while at the University of York (see Section 2).

There were two fundamental design goals: (1) The real-time behaviour of systems built using the RTOS must be fully analysable using schedulability analysis tools. In other words the behaviour of the RTOS must match the assumptions of the underpinning schedulability analysis techniques. (2) The memory and execution time overheads of the RTOS must be significantly less than those of any other RTOS available for use in automotive applications.

Robert Davis led the team that developed the SSX5 RTOS and associated schedulability analysis tools (originally called the "Time Compiler", later "Real-Time Architect (RTA)"). The schedulability analysis tools implemented Response Time Analysis as introduced by the underpinning research [1], [2], [3], [4], and [5]. The SSX5 RTOS was developed precisely to meet the assumptions of this analysis. The execution time overheads were minimised and made constant, independent of the number of tasks, allowing them to be accurately measured and this data used in the schedulability analysis. The memory overheads of applications built on SSX5 were radically reduced by comparison with other automotive RTOS. This was achieved via the use of single-stack execution and compile time, i.e. off-line, configuration of the RTOS data structures to minimise RAM usage.

NRTA attracted significant venture capital funding in 1998 (£1 million from 3i) and again in 2000 (£9.2 million from 3i and TecCapital). In 2001, the company changed its name to LiveDevices Ltd.

In March 2003 LiveDevices was sold to ETAS GmbH, a wholly owned subsidiary of Robert Bosch GmbH. The reason for the trade sale was that Robert Bosch had benchmarked RTA-OSEK and found it to be significantly more efficient than its subsidiary's Ecos RTOS. Rather than attempt to write a new OSEK RTOS from scratch and compete with LiveDevices, ETAS chose to buy the company, bringing the RTA-OSEK technology and the 20+ LiveDevices engineering team in-house.

Standards:

During the development of the SSX5 RTOS, the automotive industry was working on standards via the OSEK organisation. As a Technical Committee Member of OSEK [8], NRTA influenced the OSEK OS standard [9] ensuring that the basic conformance classes (BCCx) could be achieved with a single-stack RTOS, leveraging the execution time and memory savings which that approach facilitates. NRTA modified the SSX5 RTOS to comply with the OSEK standard, in the process renaming the product RTA-OSEK.

Subsequently, ETAS, as a premium partner [10] of the AUTOSAR (AUTomotive Open System ARchitecture) partnership, have been heavily involved in specifying the AUTOSAR operating

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system standard [11], which extends the OSEK operating system standard. ETAS derived an AUTOSAR compliant RTOS called RTA-OS from RTA-OSEK [6]. (Note in [6] RTA-OSEK 'Planner' is the new name for the schedulability analysis tools, while 'Builder' is the name for the off-line configuration tool).

Beneficiaries:

Use of the RTOS and its associated schedulability analysis tools has benefitted automotive manufacturers and their Tier 1 suppliers in the following ways: (i) A reduced memory footprint means that cheaper microcontroller variants with smaller on-chip RAM / Flash memory can be used. This has reduced unit costs in production. (ii) The very low execution time overheads of the RTOS mean that more functionality can be included on a given low cost microprocessor reducing costs by avoiding the need for hardware upgrades to more capable but expensive devices. (iii) A reduction in the time spent debugging intermittent timing issues. Schedulability analysis and appropriate use of proven real-time mechanisms have enabled off-line analysis of task response times, reducing system integration time and testing effort, and improving reliability. For these reasons the world's major ECU suppliers and car manufacturers have adopted this technology. In a competitive market, some of these benefits will have been passed on to their customers in the form of cheaper, more reliable vehicles.

The Automotive Electronics market is both huge and highly competitive, with electronics now contributing 15-30% of overall vehicle production costs. For the reasons given above, the world's leading Automotive OEMs and Tier-1 suppliers have adopted the RTA-OSEK and RTA-OS operating systems. They have done so for the substantial benefits it brings to them and to their customers.

The technology has led directly to the creation and sustaining, throughout 2008-2013, of over [TEXT REMOVED FOR PUBLICATION] high technology jobs in York [7]. The fact that ETAS has offices in York is a direct consequence of the underpinning research as described in the narrative. (Note ETAS is head-quartered in Germany and has offices in 12 other countries).

5. Sources to corroborate the impact (indicative maximum of 10 references)

[6] http://www.etas.com/en/products/rta_software_products.php,

http://www.etas.com/en/products/rta_osek.php, http://www.etas.com/en/products/rta_os.php

[7] Director of Product Management - Software Engineering and Prototyping Solutions, ETAS Ltd.

[8] http://portal.osek-vdx.org/index.php?option=com_content&task=view&id=8&Itemid=11

[9] <http://portal.osek-vdx.org/files/pdf/specs/os223.pdf>

[10] <http://www.autosar.org/index.php?p=2&up=1&uup=2&uuup=0>

[11] http://www.autosar.org/download/R4.1/AUTOSAR_SWS_OS.pdf