Impact Objective

- Address the challenge of how to use innovative modelling and simulation for rigorous design and analysis to rapidly and reliably integrate substantially increased levels of digitally-enabled functionality into the vehicle as a complex system

Leading the way

***Professor Charles Dickerson, David Battersby, Dr David Mulvaney, Dr Siyuan Ji** and **Ian Knight** highlight the importance of advanced systems engineering concepts and how their novel work is leading the way in expanding systems engineering from its origin in defence to the commercial world*

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Professor C Dickerson

David Battersby

Dr David Mulvaney

Dr Siyuan Ji

Ian Knight

What are your research interests and how do these help to meet the challenges of the 'Analysis of the Vehicle as a Complex System' project?

CD: The Loughborough University research team for this research theme in the Programme for Simulation Innovation (PSi) brings unique capabilities to meet the challenges. I am the academic Principal Investigator and bring over 25 years of experience in aerospace and defence systems engineering. I am also Co-Investigator for a complementary PSi research theme at Sheffield University. My focus for the past 10 years has been the development, formalisation and application of the Relational Oriented Systems Engineering Technology Trade-off and Analysis (ROSETTA) framework, which was developed in collaboration with Professor Dimitri Mavris at the Georgia Institute of Technology, US, during 2007-12. Complementing the background and capabilities of the university team are those of the industrial Principal Investigator, David Battersby, and the other engineers at Jaguar Land Rover (JLR) who have contributed to PSi.

DB: I am the Senior Manager for Software Architecture at JLR. I have over 20 years experience in delivering systems engineering projects in automotive and defence companies. My interest in the PSi project is to ensure that the best advanced design methods are applied to the burgeoning field of advanced automotive digital systems design.

DM: I am an academic Co-Investigator for PSi and a senior lecturer in embedded microelectronic systems. I was a founder of Axilica, a company that provided a novel tool flow for the rapid deployment of designs on embedded platforms.

SJ: I am a research associate whose academic education was in theoretical quantum physics. I have a particular interest in model-based systems engineering and systems design methodologies, tools and algorithms.

IK: I am the PSi Project manager at JLR. Before coming to JLR, I was Programme Manager for collaborative research projects at Oclaro, a tier 1 provider of high performance optical components, modules and subsystems to the telecommunications market, and I have been involved in various types of collaborative research projects of this kind for 25 years.

Can you explain the project's correlation with the PSi?

CD: PSi is a five-year research programme funded by JLR and the Engineering and Physical Sciences Research Council (EPSRC). It is a £10 million multi-university collaborative programme organised around eight research themes over the period of 2013-18. It aims to develop capability for virtual prototyping through simulation to provide manufacturers in the UK access to new, world-class simulation tools and processes.

DM: The 'Analysis of the Vehicle as a Complex System', is one of the eight research themes defined in PSi. The core of this research theme is to develop rigorous and innovative approaches to model-driven virtual design, analysis and integration of a vehicle as a complex system. This significantly extends engineering capabilities for embedded microelectronic systems. The model-driven aspect of the approach uses architectural methods that employ a formal relational framework to achieve the rigour of system development and to control the complexity of the systems of systems (SoS) that comprise the vehicle.

DB: Virtual integration in complex system design facilitates collaboration between the multidisciplinary teams of the vehicle which is regarded as an SoS. This elevates critical systems engineering activities from a single discipline of the system to an SoS level possessing multidisciplinary complexity. Achieving this capability is critical to using virtual prototyping to increase speed to market.

Could you shed light on the benefits systems engineering concepts proffer?

SJ: Systems engineering originated from defence and aerospace engineering where projects are mainly concerned with complex systems. Commercial sectors such as the automotive industry, where systems continue to grow more complex, can also be expected to benefit from systems engineering concepts. However, to fully utilise these concepts, a joint effort between the academic community and relevant industries is required to advance systems engineering methodologies and tools so that they can be readily applied in the commercial sectors. This research project is one of the leading efforts in taking this critical step toward a successful migration and advancement of systems engineering from its origin in defence to the commercial world.

What is the system of systems engineering (SoSE) approach?

CD: The advanced tools and methods developed by Loughborough University in this theme of the PSi research employ an underlying architectural formalism that is referred to as ROSETTA. This framework is a model based formalism that lends itself to the graphical languages of UML and SysML (the Unified and System Modeling Languages) used in the practice of Model Based Systems Engineering (MBSE). The formalism of the framework is rooted in the Tarski theory of models in mathematical logic; but has been adapted to the practice of engineering. The relational orientated viewpoint on systems supports a general systems methodology that employs a principle of model specification and relational transformation for the purpose of system description, analysis and design. This principle is a significant advancement over the traditional hierarchical decomposition methods practiced by systems engineers today.

How have international collaborations benefited the project?

SJ: Loughborough University has been involved with the Object Management Group® (OMG®), which is an international, open membership, not-for-profit technology standards consortium. OMG® Task Forces develop enterprise integration standards for a wide range of technologies and an even wider range of industries. The University shares new concepts with the model-based systems engineering community in the OMG®; and the software engineering community in the OMG® provides valuable feedback on the commercialisation of tools being developed by the University. For example, OMG® sets standards on UML Profiles such as the ROSETTA Profile. The commercialisation of software tools employ such profiles.

IK: Airbus and the US National Institute of Standards and Technology (NIST) have also been involved with Loughborough University through the OMG® in the development of the UML Profile for ROSETTA. Airbus also shares a common interest in architecture optimisation.

The project is currently approaching the end of its five-year duration. Have you met your primary objectives?

CD: The project has been successful in developing analysis methods that add value to the design process for complex interacting systems. Specifically: a ROSETTA facility for constraint driven design has been implemented in MATLAB®; a foundational facility is being developed for commercialisation using the UML profile; a Technology Assessment Framework has been developed to accommodate expert opinion; a relational orientated approach to model-based systems engineering and an architecture trade-off and optimisation methodology has been developed; computationally efficient algorithms to simplify complex design spaces have been demonstrated, as have self-adaptive coordinated control architectures for vehicle motion management; and architecture trade-off and optimisation capabilities have been initially demonstrated.

Are there plans to continue building upon the success of this project?

DB: JLR intends to use the methods developed to understand complex interactions between systems and as such ensure these systems are optimised to meet customer needs. This will be especially valuable in the early R&D phases when it is too early to build prototypes into cars.

SJ: The proposed foundational facility based on the UML Profile will be capable of hosting advanced design algorithms for complex constraint-driven design problems with many-design constraints and many-design variables. It will be validated using commercial quality data sets for constraint driven design trade-off analyses across multiple domains. Ultimately the facility will enable services across multiple domains for architecture optimisation and complex system design.

Advancing the automotive industry

A collaborative and innovative research project is making impressive headway in advancing the state of the art in complex system design and virtual prototyping in the automotive industry

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Advanced automotive digital systems design and integration is a burgeoning field facing multifaceted challenges. A group of researchers is striving to equip multidisciplinary teams with the tools and methods needed to make headway in overcoming these challenges.

Professor Charles Dickerson is Principal Investigator of the 'Analysis of the Vehicle as a Complex System' project, which is a research theme in the Programme for Simulation Innovation (PSi). It began in 2013 and will conclude in 2018. 'These five years complete a second major milestone in my research over the past 10 years, which began with an appointment as the Royal Academy of Engineering Chair of Systems Engineering in 2007,' Dickerson explains. 'The first milestone was when five years of research sponsored through the Academy and others (2007-12) delivered an advanced system engineering framework and methods that have now been applied to the challenges faced in the automotive and aerospace industries.'

FURTHERING THE FIELD

PSi is co-sponsored by the Engineering and Physical Sciences Research Council (EPSRC) and Jaguar Land Rover (JLR). This research theme led by Loughborough University in the UK is one of eight in PSi. As part of PSi, 'Analysis of the Vehicle as a Complex System' is assisting in advancing the field of complex system design and prototyping in the automotive industry. To do this, the researchers involved are working to develop new tools, algorithms and methods that they hope will bring new capabilities which can support multidisciplinary teams to solve complex system design problems.

Working alongside Dickerson are Co-Investigator Dr David Mulvaney, Research Associate Dr Siyuan Ji, industrial Principal Investigator David Battersby the Senior Manager for Software Architecture at JLR, and Ian Knight, who is the PSi Project Manager at JLR. 'The industrial partner JLR brings real-world challenges associated with building complex and highly interacting digital systems. The research group at Loughborough University brings advanced system engineering tools and methods that can be used to address these challenges,' Knight says as he talks about the project's multidisciplinary nature.

ENHANCING CAPABILITIES

The key goal of the work is to develop advanced design and analysis capabilities for a high-interaction vehicle as a complex system. In order to achieve this, four objectives were set. These were to: develop architectural approaches to resolve issues of complexity; implement an environment that integrates simulation within the design and analysis environment; develop advanced system modelling and analysis capabilities; and apply the advances to two case studies to demonstrate the capabilities.

These case studies were concerned with (i) engine emissions reductions and (ii) vehicle motion management. 'Both case studies addressed a challenge that faces automotive manufacturers: the problem of meeting customer expectations in the context of design constraints,' explains Battersby. The case study on engine emissions reduction addressed the customer expectation for lower fuel consumption while manufacturers must adhere to emissions regulations that are becoming increasingly strict. The case study on vehicle motion management, meanwhile, looked at the longstanding research field of vehicle motion control. The outputs of this case study were coordinated control architectures that overlay onto a distributed electronic architecture.

THE COMMERCIALISATION CHAPTER

PSi is now nearing completion and, as such, the research on the Analysis of the Vehicle as a Complex System is moving into a commercialisation phase. Thanks to the project, JLR now has access to objective analysis methods that have been demonstrated to add value to the design process for complex interacting systems. Key successes achieved include the development of a family of algorithms for emission control, known as the ROSETTA axiomatic design algorithms (RADA). In addition, the UML Profile for ROSETTA (UPR) offers a foundational facility to integrate constraint driven design algorithms such as RADA. Dickerson highlights the benefits of these major milestones as 'an exploitation path for applying RADA to electronic vehicle architecture (EVA) trade-offs and architecture optimisation has been established'. Commercialisation of UPR for future application to EVA will begin in April 2018, which is an exciting next stage for this collaborative project team.

Project Insights

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ORGANISATIONS

- Loughborough University (UK)
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COLLABORATIONS

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Object Management Group (USA)
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BIO

Professor Charles E Dickerson is the Royal Academy of Engineering Chair of Systems Engineering at Loughborough University. His research and design experience includes MIT Lincoln Laboratory, the Lockheed Skunkworks and Northrop Advanced Systems. He has also been Aegis Systems Engineer for the US Navy Ballistic Missile Defense Program. Dickerson is Chair of the Mathematical Formalisms Group at the OMG and Assistant Director for Analytic Enablers at INCOSE.

JAGUAR LAND ROVER EPSRC Engineering and Physical Sciences Research Council OMG OBJECT MANAGEMENT GROUP Loughborough University UNIVERSITY OF LEEDS The University Of Sheffield.