Institution:	The University of Liverpool
Unit of Assessment:	UoA12 Engineering
Title of case study:	Unlocking manufacturing competitiveness by increasing digital engineering literacy: enabling reality from research
Period when the underpinning research was undertaken: 2010 – 2020	

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
GD Padfield	Professor	2000 – 2011
JE Cooper	Professor	2007 – 2012
MD White	Professor	2000 – present
KKB Hon	Professor	2000 – 2015
M Jump	Senior Lecturer	2003 – present
AJ Robotham	Director, Virtual Engineering Centre	2010 – 2012

Period when the claimed impact occurred: 1st August 2013 – 31st July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Virtual engineering research at the University of Liverpool has underpinned the development of the Virtual Engineering Centre (VEC) which has worked with UK industry leading to:

Economic Impact via engagement with over 500 SMEs, creating 150 jobs and safeguarding a further 242. The value of arising goods and services from LCR 4.0 is GBP10,000,000.

Impact on Practice through the targeted adoption of new digital technologies and processes and the delivery of new digital supply-chain technology and expertise. These are exemplified by: a reduction in new automotive product development times of 6 months; delivery of a mixed-reality training tool, saving GBP20,000,000 in costs; and nationally recognised digital adoption programmes for Small-to-Medium Enterprises (SMEs).

2. Underpinning research

State-of-the-art virtual reality/modelling & simulation facilities are expensive. The Virtual Engineering Centre (VEC) was created to deliver industry-accessible digital testbed facilities, alongside the necessary associated user expertise, to allow SMEs to become part of Original Equipment Manufacturer (OEM) digital supply chains, to boost economic growth and productivity.

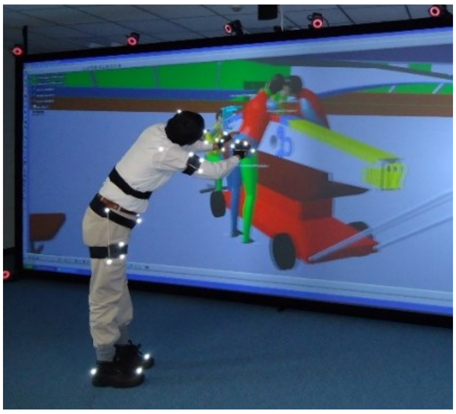

Figure 1. Early interactive VR research using the VEC PowerWall

Building on the University of Liverpool's strength in aerospace-related modelling and simulation, the VEC was established in 2009 (see Figure 1) as one of the first digital accelerator test-beds, for the development, testing and demonstration of new digital technologies, targeted towards industry. This challenge is described in [5.1]. Subsequently, this approach – developing and proving new processes and technologies in an agile but low-cost environment – has been replicated widely elsewhere, both in the UK and globally.

The key challenges to be addressed when setting up the VEC digital test-bed laboratories were threefold; to understand *(i)* how virtual environments could be usefully implemented at full-scale projection to provide a truly immersive experience; *(ii)* how virtual environments should be optimally configured to provide the required cues to give a user experience that maximises their performance and *(iii)* how the laboratories could be configured to allow shared simulations whilst protecting OEM/SME commercial confidentiality. Each of these challenges was addressed by University of Liverpool research.

Challenge *(i)* poses the research question of whether a true 1:1 scale representation of the virtual product could be produced to enable the operator to trust and believe in the virtual image being presented to them? This was addressed in [3.1] which investigated the use of 1:1 scaling for true perspective displays using a large stereoscopic screen and optical tracking system. Various vehicle models of differing fidelity were used to test the capability of the system. The ideal model size as well as design tools to augment the user's immersive experience were identified. This work provides critical evidence to support the VR Training, LCR4.0 and STRIVE impact examples described later.

Challenge *(ii)* was investigated in [3.2, 3.3]. Immersive virtual environments are increasingly used for visualization, in training, mission rehearsal and rehabilitation. Humans actively maintain postural equilibrium in everyday life, and the mechanism for this may be attributable to cortical involvement. However, externally generated visual motion signals can cause the illusion of self-motion and [3.2] found that automatic postural responses are strongly influenced by the configuration and interpretation of the surrounding environment and draw on multisensory representations. The research showed that unwanted postural responses could be minimised by providing either attended virtual or unattended physical objects within the participant's field of view or by providing auditory, visual or tactile anchor points.

Some cues are easier to deliver in a virtual environment than others. For example, colour and sound cueing is easier to deliver than the weight of an object. For this reason, it is sometimes necessary to provide substitute cues to enhance informational content in a simulation at the expense of simulation fidelity. [3.3] shows that increasing the informational content of a simulation, even if it disrupted its fidelity, enhanced the user's performance and overall experience. The use of substitute cues in virtual design environments was therefore recommended as an efficient method to achieve this goal. The work of [3.2] and [3.3] provide evidence for the veracity of the methods used in all of the Impact examples provided.

Challenge *(iii)* was explored and resolved in [3.4] and [3.5]. In order for the VEC to provide a 'neutral' space for SMEs and OEMs to meet, to discuss requirements and to showcase their technology solutions, it was important that a means was devised to allow SME component solutions to be brought in to larger OEM simulations without compromising the commercial sensitivities of either. University research created a proof-of-concept laboratory (Virtual Engineering Simulation Laboratory, VESL) at the VEC for this purpose. Formalised methods for model checking and mission planning [3.5] showed, for the first time, how rational agents could be used to replace human pilots. Crucially, each element of the simulation environment was networked through an independent data exchange hub that did not require the details of the individual model components to be shared with the others. Only the data relevant to the simulation needed to be broadcast to the simulation-at-large. The test-bed laboratory was created to allow faster-than-real-time and real-time simulation (see Figure 2).

Figure 2. Real-time networked simulation prototype visualised on the VEC PowerWall

3. References to the research

[3.1] Shao F, Robotham AJ, Hon BKK, 2012, *Development of a 1:1 Scale True Perception Virtual Reality System for design review in automotive industry*, Proceedings of the 10th International Conference on Manufacturing Research ICMR 2012 http://hdl.handle.net/10292/5012

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The VEC was financed by GBP2,500,000 from the Northwest European Regional Development Fund (ERDF), GBP1,180,000 from the Northwest Regional Development Agency (NWDA) and GBP1,640,000 from the University of Liverpool, including GBP200,000 of support from Science and Technology Facilities Council (STFC) which hosted the centre at Daresbury Laboratory, through access to its large computational science and engineering machines and software engineers.

4. Details of the impact

The impact was achieved via City Region and national industrial interventions, to maximise the benefits of increasing adoption of digital technology. These interventions resulted in positive economic, productivity and training outcomes within the current REF period and is cited by government as an exemplar in meeting the UK vision for e-infrastructure in [5.1].

Figure 3. Operator using VR training simulator – now standard practice at Sellafield

i. Training using VR technology. Sellafield have adopted a Virtual Reality (VR) simulation environment, developed by the VEC, to train and ensure the safety of the specialist operators of its recently commissioned nuclear waste removal facility. Building upon the findings of [3.1 - 3.4]. A precisely scaled immersive simulator of the waste silo and crane was created using a mixed reality model. It provides a realistic, but safe environment for Sellafield's operators to learn to 'drive' the nuclear waste retrieval crane. The real, high-cost, large-scale manipulation equipment can therefore be fully deployed on live tasks and does not have to be taken off-line for training purposes. Consequently, a significant operational cost reduction was achieved. Adoption of the simulator has saved GBP20,000,000 by freeing-up physical training infrastructure for operational use. A second key impact is the risk reduction to the business and the individual operator by allowing a new or returning worker to practice their skills 'safely' in the virtual world prior to operating in the real world. The mixed reality simulator was highly commended in the 'Safety in Innovation category' at the Nuclear Decommissioning Authority's Safety and Wellbeing awards [5.2].

ii. LCR 4.0 (https://lcr4.uk/). The ERDF part-funded LCR4.0 project supported the industrial digitalisation of small and medium-sized companies within the Liverpool City Region. Using the outputs of the research and proof-of-concept laboratories from [3.1 – 3.5], it has provided almost 300 SMEs with the tools and resources to explore the opportunities and challenges of Industry 4.0 technologies, such as systems integration, Internet of Things (IoT), augmented reality (AR) and 3D printing. A 2019 review of LCR 4.0, by Hatch Regeneris [5.3], found that 82% of SMEs said the programme changed their understanding of Industry 4.0 and enhanced their capacity to innovate (85%); over two thirds of businesses said it helped them to bring a product to market more quickly and three quarters were encouraged to be more ambitious. By June 2019 GVA was up to GBP 10,500,000 with 125 FTE jobs [5.3]. Human Recognition Systems (HRS), a Liverpool-based biometric security firm, engaged with the project. HRS developed its MSite Touch system to reduce the component costs of one of its core products by 20% [5.4], estimating a resultant GBP130,000 saving to the business over the following two-year period. HRS also reported that the project helped it to retain product effectiveness and to identify methods to improve the scalability of the product. The LCR4.0 project has featured as an 'exemplar project' in [5.5], demonstrating the value of such projects on the local business community and specifically, those in manufacturing. It has also featured in the Financial Times' 'Top 100 European Digital Champions' list [5.6].

iii. STRIVE (http://www.striveproject.org.uk/). STRIVE (Simulation Tools for Rapid Innovation in Vehicle Engineering) was a three-year collaborative R&D project, part-funded by AMSCI (Advanced Manufacturing Supply Chain Initiative), to deliver a new digital supply chain to develop globally competitive products. Building upon the findings of [3.1 – 3.3] and using the concepts proved in [3.4, 3.5], the VEC led work, in conjunction with the Northern Automotive Alliance (NAA), bringing together the SMEs: OPTIS; DNA Agile; and Valuechain.com, to provide collaborative, integrated solutions addressing challenges faced by Bentley Motors. STRIVE enabled Bentley to reduce new product development timescales from 54 to 48 months, whilst enhancing build quality. This was achieved by implementing bespoke virtual technologies into the Bentley Motors process, Figure 4. It created and safe-guarded over 40 highly-skilled roles at Bentley, 11 at Optis and 4 at Valuechain.com. STRIVE won the 'Education in Business' Award at the 2016 North West Business Insider 'Made in the North West' Awards [5.7]. The Award recognised the benefits spanning: job creation; career development and the meeting of strategic production time reduction targets. Responding to the award, Manufacturing Project Leader for Continental & Flying Spur at Bentley Motors stated:

Figure 4. Bentley engineers using VEC-developed interactive VR sandpit to review a new SUV product

"*The positive impact on the business gained from the deployment of the new toolsets at the Bentley site has been a direct result of this innovative collaboration between us, the University's Virtual Engineering Centre and agile North West based SMEs. Existing 'off the shelf' hardware and software solutions, including toolsets already in use, did not offer the 'step change' we have achieved through STRIVE*…"

To date, 4 new products (1 new car model and 3 software tools) have utilised the STRIVE toolset. In addition, a digital quality assurance inspection process has been developed at Bentley using STRIVE. The benefits are described by Bentley's Head of Pre-Series Manufacturing in [5.8].

iv. GAMMA (http:// aerospace.co.uk/technical/gamma-programme). The Growing Autonomous Mission Management Applications (GAMMA) programme was launched in 2012 to help the autonomous supply chain avoid market failures for innovative products. An unforeseen issue with one of the key industry project partner's ability to deliver software to the project placed a much greater emphasis on the role of the VEC's synthetic environments, allowing GAMMA to engage with a wider range of autonomous applications and SMEs [5.9]. Figure 5 shows networked simulation capabilities, developed as part of the work reported in [3.4] and [3.5], being demonstrated in a VEC virtual lab, to an audience including representatives from academia, industry and government. Funded through a Regional Growth Fund (RGF) grant and in-kind contributions from delivery partners, GAMMA delivered 24 projects with 18 SMEs, creating nearly 18 direct and an estimated 298 indirect jobs with a value of GBP4,900,000 GVA per annum [5.10]. GAMMA offered project funding, mentoring and technology development support. Fifteen projects were showcased to potential end users and 10 market exploitation or development plans were delivered. The University of Liverpool partnered with the North West Aerospace Alliance, BAE Systems and the National Nuclear Laboratory as well as other regional universities.

Figure 5.Networked simulation allowing academia, SMEs, Primes and Government to interact

5. Sources to corroborate the impact

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[5.3] LCR4.0 – Summative Assessment Report, Hatch Regeneris, 18/07/19 .pdf. Reviews impact of project including: technical p32-p34, financial and employment p40.

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