Institution: University of Strathclyde

Unit of Assessment: 12

Title of case study: Improved efficiency and design practice in European maritime industry.

1. Summary of the impact (indicative maximum 100 words)

The impact relates to improved productivity, operational efficiency, working practice and knowledge management within the European maritime industry through the use of a Virtual Integration Platform (VIP). The platform is a software package developed within the University of Strathclyde that has been used by eleven European ship design, engineering and project management consultancies, which specialise in the application of advanced computational design, analysis and physical modelling techniques within projects on an international scale. Specific company benefits of using the VIP include: 67% reduction in process time; guaranteed data consistency; additional productivity of 15 hours/day from automated over-night operation; capturing and reuse of expertise; cost effectiveness (lack of data consistency typically costs €100k per project); and ease of operation within complex design processes.

2. Underpinning research (indicative maximum 500 words)

Context: In the collaborative design of complex manufactured systems such as ships, effective product data management is extremely challenging when applied across organisationally and geographically distributed designers and analysts. The lack of effective support by existing solutions has been reported to cost the general US industry "billions of dollars" (Szykman et al., Source E). The management required in order to overcome these challenges exists within three layers: conceptual, physical and data management. Previous research by others has focussed on defining product data standards which have required significant development effort and expertise for implementation, resulting with industrial uptake that had minimal impact (Gielingh, Source F). In contrast, the Virtual Integration Platform (VIP) is a transformative platform that provides unique support for the collaborative design and analysis of complex manufactured systems such as ships and aircraft, and provides an integrated solution to these challenges through: translation and transfer of product data between tools; user-centred integration support; transaction management, access and version control; and change notification. The VIP was the first realisation of a fundamental architecture for a maritime Integrated Design Environment that would support distributed design. It has been developed exclusively within Strathclyde over a twelve year period within a number of EU funded projects (see also Section 3):

- VRShips-ROPAX 2001-2005. The concept for the VIP was devised exclusively within Strathclyde, and the platform developed collaboratively between Strathclyde (approx. 70%), National Technical University of Athens (approx. 20%), and Instituto Superior Téchnico (approx. 10%). Dr Whitfield was the principal system architect for the duration of the project.
- VIRTUE 2005-2009. The evolution of the VIP was devised and developed exclusively within Strathclyde with Dr Wu being the principal developer and system architect until 2007 and subsequently Dr Whitfield from 2007-2009.
- SAFEDOR 2005-2009. The VIP was devised and developed exclusively within Strathclyde with Dr Whitfield being the principal developer and system architect for the duration of the project. It was this version of the VIP that was used to achieve the impact described herein.
- EuroVIP 2011-2014. The focus of the EuroVIP project is the promotion of collaboration and the use of the VIP throughout industry, and not specifically VIP development.

Key findings: Research within Strathclyde on co-ordinating distributed design resulted in the creation of: a solution for ship product data integration [1]; a framework and solution for distributed design co-ordination [2, 3]; a solution for the management of distributed design resources [4]; techniques for the management of extremely large design models [5]; and, a platform for integrated risk and cost-based design [6].

The first development of the VIP within the VRShips project implemented a generic integration solution for over twenty ship design and analysis tools to support through-life design. The VRShips innovation was a radical modelling solution for structuring and managing the volume of engineering product data for complex manufactured systems such as ships; the project also resulted in the creation of a generic integration tool for design and analysis software aimed at ship designers rather than commercial software developers. These two solutions provided the core functionality that was needed to support the through-life design of ships [4]. The solution was unique in that no other product data management solution provided this level of integration within the industry

without being reliant on cumbersome product data and integration standards. The project demonstrated that the VIP concept was viable and highlighted the need for a number of enhancements that required further research to broaden the scope of industrial implementation. The VIP evolved within the VIRTUE project which focussed on integrating Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD) tools and providing solutions to physical, and data management interoperability challenges. One of the greatest challenges related to the management of extremely large CFD datasets, which required the creation of a novel distributed data management solution that automatically propagated design change and maintained consistency of multiple versions of ship product data. The platform evolved through close industrial engagement (by an implement/test/evolve cycle) to support more efficient and effective collaborative design.

SAFEDOR demonstrated that first principle CAD and analysis tools could be integrated into the VIP to change the way that ships were designed and optimised for safety. This represented a radical change to the design process: adopting goal-based optimisation, rather than rule or regulation based design. Evolution of the VIP also demonstrated that a novel "dependency network" could provide a more effective way of supporting decision making relating to the design process, and provide more user-centric support for managing and visualising the exchange of product data than would otherwise be possible within more conventional workflows.

Key researchers within the Department of Design, Manufacture and Engineering Management, University of Strathclyde were Prof A.H.B. Duffy (Reader 1998 - 2004, Professor 2004 - present); Dr R.I. Whitfield (Senior Research Fellow 1998 - 2007, Lecturer 2007 - present); Dr Z. Wu (Research Fellow 2002 - 2007). Prof D. Vassalos was Professor in the Department of Naval Architecture and Marine Engineering 1996 - present. Other key researchers were Dr J. Marzi (HSVA), for VIRTUE and EuroVIP.

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

References 1, 4, and 5 best exemplify the quality of the body of research. References 1 and 5 are being returned within the UoA 12 REF2 submission.

[1] R.I. Whitfield, A.H.B. Duffy, P. York, D. Vassalos, P. Kaklis, Managing the exchange of engineering product data to support through-life ship design, Journal of Computer-Aided Design, 43 (2011) 516-532.

[2] A.H.B. Duffy, M.M. Andreasen, K.J. MacCallum, L.N. Reijers, Design Coordination for Concurrent Engineering, Journal of Engineering Design, 4 (1993) 251-265.

[3] G. Coates, A.H.B. Duffy, R.I. Whitfield, W. Hills, Engineering management: operational design co-ordination, Journal of Engineering Design, 15 (2004) 433-446.

[4] R.I. Whitfield, A.H.B. Duffy, G. Coates, W. Hills, Distributed design co-ordination, Research in Engineering Design, 13 (2002) 243-252.

[5] Whitfield, R., Duffy, A., Gatchell, S., Marzi, J., & Wang, W. (2012). A collaborative platform for integrating and optimising Computational Fluid Dynamics analysis requests. Computer-Aided Design, 44(3), 224–240, doi: 10.1016/j.cad.2011.04.004

[6] W. Wang, A.H.B. Duffy, R.I. Whitfield, K. Mohamed, H. Prins, S. Gatchell, Virtual Integration Platform for Computational Fluid Dynamics, in: 14th International Conference on Computer Applications in Shipbuilding, Royal Institution of Naval Architects, Shanghai, China, 2009.

Other evidence for quality of research (grants, patents etc.)

- VRShips-ROPAX (EU FP5, 36 partners, 2001-2005, €11.8M total, Technology Platform Project: GRD1-2000-25709; £1,100,000 awarded to Strathclyde).
- VIRTUE (EU FP6, 22 partners, 2005-2009, €17.4M, funded Sustainable Growth and Development project: TIP5-CT-2005-516201; £1,018,000 awarded to Strathclyde).
- SAFEDOR (EU FP6, 53 partners, 2005-2009, €20M, funded programme: TIP-CT-2005-516278; £1,095,000 awarded to Strathclyde).
- EURO VIP (EU FP7, 17 partners, 2011-2014, €1.8M SST-2010-266054; £367,000 awarded to Strathclyde).

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

Process from research to impact:

The VRShips, VIRTUE and SAFEDOR projects had a combined and general theme of integrating advanced information technology into the collaborative design of ships. The projects were

industrially driven, with responsibility for applying the VIP being held by eleven associated maritime consultancies (detailed below). The VRShips project demonstrated that the VIP concept was viable for supporting European shipbuilding by focussing on capturing industrial requirements and needs, and prototyping the initial platform. The focus within VIRTUE and SAFEDOR was a fundamental shift in product data management to satisfy the identified industrial challenges and needs, and implement the VIP in industry. This industrially driven implementation ensured that the partners had the responsibility to deliver the case study demonstrations; had first-hand use of the VIP within their organisations; applied the VIP to their own problems; and were driven to exploit the opportunities that the VIP provided within the context of the case studies and also within further use within their organisation. These organisations were, therefore, adopting the research output (the VIP), adapting their ways of working by integrating their design and analysis tools into the VIP, and subsequently improving the way they operate. The success of the VIP development and more importantly, the industrially-driven implementation is highlighted within the VIRTUE final project review relating to the VIP: "*The Reviewers are pleased that excellent progress has been made and many user requirements set up during the project have been included, hence demonstrating large functionality which is indicated through the large number of test cases which have been provided and shown by the partners*"; Source A.

Types of Impact: The VIP has been applied within the VIRTUE, SAFEDOR and EuroVIP projects by world-leading European ship design, engineering and project management consultancies, that undertake projects on an international scale including: Arsenal (Portugal), Atkins (UK), ECN (France), Friendship Systems (Germany), HSVA (Germany), Insean (Italy), MARIN (Netherlands), Principia (France), Sirehna (France), SSPA (Sweden), and ZIB (Germany). Collaborative applications have included (and were led by): wave resistance studies (Scott Gatchell, HSVA), hydrofoil design and optimisation (Christine de Jouëtte, Principia), propeller design (Scott Gatchell, HSVA), sea-keeping (Christine de Jouëtte, Principia), hull/propeller interaction (Francesco Salvatore, Insean), and hull shape optimisation (Christophe Malibat, Atkins). Through this industrial implementation of Strathclyde's VIP, the enhancements to engineering design practice are exemplified through implementation in HSVA and MARIN. HSVA is a privately owned service and consultancy company with 21 shareholders, 90 employees, based in Hamburg Germany with customers worldwide. HSVA specialises in testing technology, methods, standardisation and numerical procedures to solve complex problems, and has a turnover of €10-12M, 56% of which is international. MARIN is an international leading provider of hydrodynamic and nautical research and development, based in Wageningen, The Netherlands, employing 350 people with an annual turnover of €42M of which 85% is realised by commercial projects for the international maritime industry. Marin provides innovative design solutions and advanced research to a wide range of international customers. The implementation of the VIP has had the following beneficial impact:
Improved efficiency: the VIP allows designers greater opportunity to focus upon design and analysis activities rather than the management of the process. Traditional integration approaches using technologies such as the Common Object Request Brokerage Architecture were not end-user oriented having a steep learning curve, were complex and hard to use correctly, and resulted in long development times and high defect rates (Henning, Source G). The Strathclyde platform delivered time savings with the same quality of delivery as other approaches to meet customer requirements, as exemplified by the comments from MARIN's R&D Manager:

- "*It took only three hours for a first-time user to be familiar with the platform, build up the process and finish configuration. Overall, designers in MARIN were positive about the applicability of the VIP in the future CFD computations*"; Source B.
- "*Time efficiency was significant. Automation of the workflow and data flow [within the VIP] resulted in the run time of the process being reduced from six to two days, which was a 67% time reduction*"; Source B.

Improved productivity: the platform supports both manual and automated design and analysis activity to be coordinated in a distributed manner with a view to best exploit the resources available. Productivity improvements are exemplified by comments from HSVA and MARIN:

- "*Allowing the process to run autonomously overnight could evaluate hundreds of design variations over a multiple parameter search field. Additionally, less time was required from the "expert user", especially for the in-between steps, where little decision-making was required";* Source C. *"This automation resulted with fifteen hours [per day] of achievement or progress*

that would otherwise be wasted if the design was performed manually"; Source C.

- "*The VIP users found it especially useful to automatically produce analysis reports following each analysis. It saved time for the designers by avoiding composing such reports, hence enabling them to focus on more design related tasks*"; Source B. "*The time saved automatically producing reports was in the region of hours for each report created*"; Source B. MARIN would typically create over 1000 reports each year resulting in a minimum annual saving of 2000 hours effort.

Improved working practice: the platform provided data and process integration that saved manual effort and ensured data consistency and integrity as reported by HSVA and MARIN:

- "*The VIP facilitated the improvement of legacy tools as a direct result of integrating the tool into the platform, which shows that the VIP can also be used for testing CFD/design tools being developed. The tools were expanded to include more interoperability options for input and output formats, in some cases for more adherence to a common data format. The VIP provided automation that eliminated the need for the user to manually input certain values*"; Source C.
- "*The VIP guaranteed data consistency across resistance, manoeuvring, and sea keeping calculation of the hull. Moreover, by storing the correct configuration of the tools used in this project in the platform, errors caused by human carelessness were eliminated*"; Source B. "*The likelihood of inconsistent data is very low due to project management practices, however the consequence is significant and can cost in the region €100k, easily outnumbering the costs of investing within such a platform*"; Source B.

Enhanced knowledge reuse: HSVA has reported that through use of the VIP valuable specialist designer time is released to focus on more value-added activities:

- "*By saving and reusing configuration files, the "know how" knowledge of expertise was captured and reused by non-specialist users. The VIP enabled error free enactment for non-specialist users to enact a process that previously could only be done by specialists*"; Source C.
- "*The specialist's expertise is only required at the end for a final evaluation to approve the outputs, and to provide assistance in resolving unusual results; this frees up the specialist to focus on suitable and meaningful work*"; Source C.

Wider adoption: The successes and advances that have been achieved through these projects led to the creation of the EU FP7 funded EuroVIP project which uses the VIP to exploit new developments, by partnering and collaboration throughout the European maritime sector. The focus is to broaden the reach of implementation for the VIP and promote collaboration which has now resulted in 64 European wide registered users including seven associations, the latter providing a conduit to over 1500 companies across Europe. The University of Strathclyde is also currently in discussion with Astrium Space Transportation (Source D) who have identified the VIP as being a promising technology for the Next Generation Launcher, demonstrating the generic applicability of the platform. A preliminary technology plan is being prepared to allow Astrium to lobby their partners in the adoption of the VIP, and open up implementation within an equally challenging sector.

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

A. Statement from Professor of Fluid Mechanics, Vrije Universiteit Brussel.
B. Statement from Research and Development Manager, Maritime Research Institute Netherlands.
C. Statement from CFD Specialist, HSVA Hamburgische Schiffbau-Versuchsanstalt GmbH.
D. Head of Operations for R&T Academic Partnerships TS1 can be contacted to provide evidence
E. Document: S. Szykman, S.J. Fenves, W. Keirouz, S.B. Shooter, "A foundation for interoperability in next-generation product development systems", Computer-Aided Design, 33 (2001), 545-559.
F. Document: W. Gielingh, "An assessment of the current state of product data technologies", Computer-Aided Design, 40 (2008), 750-759.
G: Document: Henning, Michi (30 June 2006). "The rise and fall of CORBA", ACM Queue (Association for Computing Machinery) 4 (5).