Institution: University of Surrey

Unit of Assessment: 11 Computer Science and Informatics

Title of case study: Enabling commercial success in the agile IoT device sector

Period when the underpinning research was undertaken: 2006 - 2015

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:
Paul Krause	Professor in Complex Systems	2001 – present
Sotiris Moschoyiannis	Senior Lecturer in Complex Systems	2006 – present

Period when the claimed impact occurred: 2015 - 2020

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

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

A range of novel methods has been developed for supporting transactions between, and collaborations amongst, agents in a distributed ecosystem of services. Since 2015, Balena (an SME that develops, deploys and manages connected devices) has benefitted from Surrey's research resulting in; company growth from 5 to 102 employees, a total of $31.4 million in funding, and a 280% increase in annual income reaching $1.9 million in 2020. Balena has also expanded its customer base, supplying solutions to a wide range of sectors, including drones and robotics, transportation, manufacturing, energy, agriculture, digital signage, and building management.

2. Underpinning research (indicative maximum 500 words)

Our ambition in the programme of research relating to this case study was to provide a formal underpinning to the development of software infrastructure for SMEs to deliver innovative services and products on a global basis. Our work covered three broad areas: (i) generation of information systems from business requirements; (ii) foundational infrastructure for the development and deployment of innovative services; and (iii) organisational aspects of distributed and agile software development.

This work, led by Krause and Moschoyiannis, was primarily funded under an EU "Digital Ecosystem" theme (2002 - 2011), applying the following Surrey-defined definition:

"A digital ecosystem is an interactive system established between a set of active agents and an environment within which they engage in common activities."

Although very general, we had a specific architecture/environment in which the agents (usually services) were governed by models expressed in the SBVR notation **[R1]**. This, in conjunction with the then-emerging move towards RESTful interfaces, enabled us to generate a suite of tools that could support service transactions within the context of a compiled SBVR model as well as the compilation of SBVR into SQL queries and persistence layer **[R2, R3, R4]**.

These afore-mentioned publications were focused on the implementation level and resulted in a suite of tools published under an open-source licence. However, we also wanted to be sure that transactions amongst multiple agents/services within this environment were well behaved and

recoverable, and so supported the architecture with more formal studies based on a true-concurrency (non-interleaving) semantics to ensure the framework would scale without the emergence of pathologies **[R5, R6]**.

While we had ambitions to embed this work in a fully open Peer-to-Peer architecture, with no central points of control or failure, the core framework still met the goals of providing a framework for deploying at scale fleets of agents whose behaviour, individually and collectively, could be easily adapted/updated via the structured natural language interface of our SBVR editor.

Our open-source tools were tested out in production during 2012. The start-up company, *Renew*, had developed bomb-proof recycling bins that could be used in busy locations. *Renew* aimed to monetise this with advertising revenue from LCD displays attached to the bins. The concept won a contract with the City of London in the lead up to the Olympic games primarily because of the potential for rapid communication with the public, via the screens, in case of an emergency scenario. Our open-source tools **[R2, R3]** were used to develop, deploy and maintain the display services across all the bins in the City, demonstrating the viability of these open-source tools for the first time, which were built upon by Balena.

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

[R1] Razavi A, Moschoyiannis S, Krause P (2009) An open digital environment to support business ecosystems, *Peer-to-Peer Networking and Applications 2* (4) pp. 367-397 Springer DOI: 10.1007/s12083-009-0039-5

[R2] Moschoyiannis S, Marinos A, Krause P (2010) Generating SQL queries from SBVR rules, *Lecture Notes in Computer Science*: Semantic Web Rules 6403 pp. 128-143 Springer-Verlag Berlin. DOI: 10.1007/978-3-642-16289-3_12

[R3] Marinos A, Krause P (2009) Using SBVR, REST and Relational Databases to develop Information Systems native to the Digital Ecosystem, *2009 3rd IEEE International Conference on Digital Ecosytems and Technologies* pp. 424-429 IEEE. DOI: 10.1109/DEST.2009.5276719

[R4] Marinos A, Razavi A, Moschoyiannis S, Krause P (2009) RETRO: A Consistent and Recoverable RESTful Transaction Model, *2009 IEEE International Conference on Web Services*, Vols 1 and 2 pp. 181-188 IEEE. DOI: 10.1109/ICWS.2009.99

[R5] Moschoyiannis S, Krause PJ (2015) True Concurrency in Long-running Transactions for Digital Ecosystems, *Fundamenta Informaticae* 138 (4) pp. 483-514 IOS Press. DOI: 10.3233/FI-2015-1222

[R6] Moschoyiannis S, Razavi AR, Zheng YY, Krause P (2008) Long-running Transactions: semantics, schemas, implementation, *Proceedings of 2nd IEEE International Conference on Digital Ecosystems and Technologies* pp. 208-215 IEEE. DOI: 10.1109/DEST.2008.4635168

Funding:

FP6-IST, 034824 (June 2006 – May 2010), £561,411, University of Surrey.

EPSRC, Evolution and Resilience of Industrial Ecosystems (ERIE), EP/H021779/1 (June 2010 – May 2016) £3,344,524, Moschoyiannis, Krause et al.

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

It is estimated that by 2022, the number of connected electronics worldwide will hit 29 billion, of which around 18 billion will occupy the burgeoning internet of things (IoT) subcategory **[S1].**

Surrey's research and development of novel methods for supporting transactions between and collaborations amongst agents in a distributed ecosystem of services underpinned the decision by Dr Alexandros Marinos – a former Surrey PhD student and PDRA – to found the start-up company Balena (formerly RuleMotion) in 2011 with the aim of commercialising research outputs from Surrey's Digital Ecosystem programme. Marinos was supported in this venture by Krause and Moschoyiannis, who together aimed to use Surrey's expertise to make managing IoT devices as straightforward as configuring PC peripherals. Both Krause and Moschoyiannis continue as advisors to this company, with Krause also being a shareholder.

Impact on Balena's product offering

The conceptual basis, and many of the technical outputs from Surrey's Digital Ecosystems research group, are deeply embedded in the products and ethos of Balena. Balena's API platform, open-sourced as "S3" **[S2, S3]** in its entirety, is a direct descendant of the work reported in **[R2, R3]**. SBVR is still used in production, and the system still compiles to SQL as described in these outputs **[S4]**. Founder and CEO Marinos states, "<...> *it remains central to our core business and has been a key facilitator of our agile way of working.*" **[S2]**

Balena's first product, launched in 2012, was a syntax-directed editor for SBVR that could compile structured natural language models to SQL **[R2]**; this remains at the core of the Balena API. The rebranding of the original company to "Balena.io" in late 2013 coincided with the full-scale launching of their support for service management in fleets of IoT devices, which exploited the service composition and transactional research of **[R1, R5, R6]**.

Balena as a catalyst for innovation

While the Balena product stack has been expanded significantly during the company's life, the Balena API remains at the heart of their IoT Infrastructure. Our research work **[R2, R3, R4]** was amongst the first to use "RESTful" ways of working with connected resources, and this remains at the heart of the Balena way of working. The use of a restricted set of verbs to interact with resources (including devices, applications, users, and more) provides a unified interface with which to interact with this diversity of resources. This way of working has almost universally replaced the baroque service-oriented architectures prevalent at the start of the new millennium. However, what made, and still makes, the API approach scalable and easy to use was the embedding of REST into a structured natural language interface using SBVR and the automated mapping into an SQL persistence layer **[R2, R3]**. This means that users of Balena do not need specialised knowledge of the service-oriented architecture and database technology in order to set up and manage a fleet of interacting resources **[S4]**.

This ease of setting up the management of a fleet of resources is an aspect of Balena that is repeatedly mentioned as a primary reason for moving to Balena by innovative IoT businesses **[S5, S6, S7]**. The robust transaction model **[R4, R5, R6]** is less visible to the SME end-users but is recognised in terms of the quality of service they can provide **[S5]**. The concept of forward recovery formalised in **[R5]** is particularly important as it enables dynamic updating of micro-services to be facilitated without loss of service. This is particularly important for safety-critical examples, such as when Balena is used to manage fleets of drones **[S5]**, with even the updating of a complete software stack having been demonstrated mid-flight. **[S5]** also reinforces how Balena enabled Skycatch to rapidly respond to a first-time request for a fleet of several hundred of their surveillance drones, scaling from the operation of small numbers to fleets of potentially thousands of drones simply through integrating Balena into their product stack.

Ease of use is especially illustrated in **[S6],** where the use of Balena was used by Figure Devices to take a prototype idea developed in a maker space into production support of hundreds of instances.

The importance of being able to support live updates of software **[R4, R6]** without "bricking" devices (making them unusable for a period) was a key driver behind OpenROV's migration to Balena **[S7]**.

However, Balena is not just a key enabler for innovation-driven SMEs. The use of Balena to support one of Europe's biggest IoT hackathons and subsequent use for Bosch's own products is described in **[S8]**. Again, the Balena dashboard features here; a core part of Balena that originated in Surrey's research programme **[R2, R3]**.

The appeal to such a broad customer base has led to an acceleration of demand for Balena; across all their customers, the number of devices supported by Balena's infrastructure grew from c15,000 in January 2018 to over 70,000 in May 2019.

Growth of Balena

Three years after moving the company's base to Washington, Seattle in 2013, it managed to attract $9 million in venture capital from Threshold Ventures, GE Ventures, Ericsson, and Aspect Ventures. With a subsequent $5 million in funding, Balena geared up for expansion, flush with $14.4 million raised in a series B round led by OpenView and existing investors. The infusion has fuelled its workforce's growth, distributed across its Seattle headquarters, satellite offices in London & Athens, and globally. The number of devices on Balena's platform is growing at a rate six times year-over-year, and that customer acquisition is on the upswing. Balena now counts Bosch, Booster, Allscripts, Tapp, Zume Pizza, OpenDoor, Sonder, smart home systems company Dwelo, smart roof start-up Sense, HVAC monitoring and controls provider Enerbrain, and smart building controls developer Mount Kelvin among its customer base **[S1]**.

Balena has now raised a total of $31.4 million in funding since April 2015 **[S10]**. The last two years, especially, have seen accelerating growth in Annual Recurring Revenue, from just under $500,000 in January 2018 to $1.9 million in May 2019. The company has grown from 5 employees in 2013 to over 100 employees, distributed globally **[S9, S10].**

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

[S1] Discussion of Balena's placement in the market for IoT device management: https://venturebeat.com/2019/07/24/balena-raises-14-4-million-to-simplify-iot-device-management/

[S2] Testimonial from Balena CEO. (PDF)

[S3] The open-source pinejs project can be found at: https://github.com/balena-io/pinejs

[S4] An example of the generation of the model layer for a new application can be found at: https://github.com/balena-io/pinejs/blob/master/docs/GettingStarted.md

[S5] Use of Balena to support fleets of drones: https://vimeo.com/393555024

[S6] Use of Balena to grow a start up from a maker space to a company supporting hundreds of product items: https://vimeo.com/128400259

[S7] Use of Balena to support live updates of software: https://www.balena.io/blog/openrov-case-study

[S8] The use of Balena to support one of Europe's biggest IoT hackathons, and subsequent use for Bosch's own products is described in: https://www.balena.io/blog/remotely-managing-and-deploying-to-iot-devices-at-scale-with-balena

[S9] Pitchbook confirmation of investment in Balena: https://pitchbook.com/profiles/company/111631-69#overview

[S10] Crunchbase Company Profile & Funding – Balena https://www.crunchbase.com/organization/resin-io