

Institution: University of Manchester		
Unit of Assessment: UoA 17 (Business and Management)		
Title of case study: Improved Software and Service Systems that Deliver Sales, Efficiency, and Access Opportunities in the European Manufacturing Industry		
Period when the underpinning research was undertaken: 2006-2019		
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:
Nikolay Mehandjiev Iain Stalker	Professor Lecturer	2006 – present 2004 - 2020 (Informatics, Materials)
Martin Carpenter	Research Associate	2015 - present (Informatics, AMBS)
Period when the claimed impact occurred: 2014 – 2020		
Is this case study continued from a case study submitted in 2014? N		
<p>1. Summary of the impact</p> <p>Software systems that enable companies to collaborate on complex manufacturing activities are increasingly vital for advanced industry. Research by Professor Mehandjiev and his colleagues has informed design of software modules and service systems that enable manufacturing companies to collaborate more effectively in the supply chain for European aerospace, for example by automatically proposing a suitable collaborative team in response to a given task. The research has been instrumental in three specific impacts:</p> <ul style="list-style-type: none"> (i) new software products, including a re-planning system that generated sales of EUR1,800,000 from Airbus; (ii) enhancing the capabilities of European supply systems, including a three-fold increase in access for SMEs to the aerospace supply chain with Hanse Aerospace; (iii) improving efficiency and effectiveness of European manufacturing, including savings of EUR10,000,000 per annum in operating costs, a 30% increase in speed of procurement and a 10% increase of throughput for Airbus. 		
<p>2. Underpinning research</p> <p>Practical applications of Artificial Intelligence have presented researchers with a number of problems. One particular issue concerns how best to automate the composition of collaborative teams using explicit knowledge about the domain of discourse and about the potential collaborators. Since 2006, Mehandjiev and colleagues have addressed this issue by focusing on two broad research questions:</p> <ul style="list-style-type: none"> (a) How can a knowledge-based software system provide the flexibility, transparency and other features required to support human team composition practices and decision-making? (b) How can we formalise knowledge about ways-of-working and allow team compositions that are not limited by the knowledge available? <p>The resultant approach and core ontology, working together to support flexible team composition, was published by Mehandjiev in 2009. This enabled Mehandjiev to subsequently research, develop and evaluate prototype software systems which led to further novel research findings.</p> <p>Firstly, Mehandjiev researched and developed an approach and underlying ontology to handling re-planning of production activities in response to supply disruptions [1, 2], which were unique in</p>		

bringing together knowledge regarding process co-ordination, manufacturing products, and goal-based task allocation.

Secondly, Mehandjiev conducted research into an innovative knowledge-driven method, collaboration ontology and a series of prototype systems for composing collaborative teams in manufacturing [1, 3, 4, 5, 6]. The method is based on a novel conceptualisation of team composition practices ensuring flexible operationalisation of allocated goals and subcontracting of sub-goals.

Thirdly, from 2012 onwards, Mehandjiev led a number of follow-on research projects with industrial collaborators which applied and refined the knowledge garnered through the above research projects to specific manufacturing sectors. The projects conducted 'research-into-practice' experiments to develop service and software systems to address specific manufacturing problems. In particular, Mehandjiev was a Co-Investigator on the EUR8,000,000 European project *Decentralised Agile Coordination Across Supply Chains* (DIGICOR, 2016-19), led by Airbus. The project focused on novel collaboration concepts for supply chains and subsequent design of an integrated digital platform that significantly enhanced the formation of collaborative production networks, including SMEs. This succeeded Mehandjiev's work on the EUR11,700,000 European project *Adaptive Production Management* (ARUM, 2012-15), which researched how planning and control systems for the manufacturing of complex products in small-lot production, such as aircraft and aircraft interiors, could be improved to handle disturbances.

Mehandjiev's contribution to these projects was to examine collaboration opportunities and barriers between companies and their supply chains [6], and use the findings as a basis for developing software systems [2,3] which can automatically propose a collaborative team that meets the requirements of a specific business opportunity, such as an invitation to tender from a major customer.

3. References to the research

- [1] Grefen P., Mehandjiev N., Kouvas G., Weichhart G., Eshuis R. (2009) Dynamic Business Network Process Management in Instant Virtual Enterprises, *Computers in Industry*, vol 60, Issue 2, 86-103, <https://doi.org/10.1016/j.compind.2008.06.006> [61 Web of Science citations]
- [2] Inden U., **Mehandjiev N.**, Mönch L., Vrba P. (2013) Towards an Ontology for Small Series Production. In: Mařík V., Lastra J.L.M., Skobelev P. (eds) *Industrial Applications of Holonic and Multi-Agent Systems*. Lecture Notes in Computer Science, vol 8062. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-40090-2_12 [Partly funded by the EUR11,700,000 European project ARUM, where Mehandjiev was a Co-I]
- [3] **Mehandjiev N.**, Grefen P. (eds) (2010), *Dynamic Business Process Formation for Instant Virtual Enterprises*. Advanced Information and Knowledge Processing. Springer, London. <https://doi.org/10.1007/978-1-84882-691-5> [45 CrossRef citations – Partly funded by the EUR2,800,000 European project *Cross-Organisational Workflow Formation and Enactment* (CROSSWORK), where Mehandjiev was the PI]
- [4] **Mehandjiev N.**, **Stalker I.**, **Carpenter M.** (2009) Recursive Construction and Evolution of Collaborative Business Processes. In: Ardagna D., Mecella M., Yang J. (eds) *Business Process Management Workshops*. BPM 2008. Lecture Notes in Business Information Processing, vol 17. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-00328-8_58
- [5] **Carpenter M.**, **Mehandjiev N.**, **Stalker I.** (2009) Emergent Process Interoperability within Virtual Organisations. In: Fischer K., Müller J.P., Odell J., Berre A.J. (eds) *Agent-Based Technologies and Applications for Enterprise Interoperability*. ATOP 2005, ATOP 2008. Lecture Notes in Business Information Processing, vol 25. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-01668-4_4
- [6] Kazantsev N., Pishchulov G., **Mehandjiev N.**, Sampaio P., Zolkiewski J. (2018) Formation of Demand-Driven Collaborations between Suppliers in Industry 4.0 Production Networks. PrePrints, 20th International Working Seminar on Production Economics, Innsbruck, Pages 255-266

[https://www.research.manchester.ac.uk/portal/files/78176280/Kazantsev et al Barriers to s
upplier collaboration in industry 4.0 a study of the aerospace sector 2018.pdf](https://www.research.manchester.ac.uk/portal/files/78176280/Kazantsev_et_al_Barriers_to_supplier_collaboration_in_industry_4.0_a_study_of_the_aerospace_sector_2018.pdf) [Partly funded by the EUR8,000,000 European project DIGICOR, where Mehandjiev was a Co-I]

4. Details of the impact

The research has led to new commercially successful products and services being developed for the European manufacturing industry, enhanced the capabilities of European supply systems and led to significant improvements to the efficiency and effectiveness of one of Europe's largest manufacturing companies. This includes a new software system, initially contracted for EUR1,800,000 and eventually leading to estimated savings of EUR10,000,000 per year and boosting throughput by 10%, which also won the Airbus Best Innovation Award for 'Research to Practice' in 2018.

4.1. New products and services in the European technology industry

CertiCon Ltd is a Czech technology company specialising in the innovation and development of software solutions for the healthcare, telecommunications, automotive and aeronautical industries. It operates in 30 countries and was an industrial collaborator with Mehandjiev on the ARUM and DIGICOR projects. This collaboration resulted in a new software product, EPIQUA, which was based on Mehandjiev's research [2,4] into how to model the knowledge underpinning systems which can re-plan production activities after supply chain disruptions [A]. CertiCon quickly added EPIQUA to its commercial portfolio. The Chairman of CertiCon, reports that "*the University of Manchester produced an ontology and an approach to handling re-planning of production activities in response to supply disruptions ... and played a key role in implementing a prototype system [EPIQUA] which demonstrated the viability of this approach and was trialled with three separate use cases*" [A].

Airbus subsequently placed orders for EPIQUA with CertiCon worth EUR1,800,000 to develop a full commercial version of the prototype [A]. The first version of the system was successfully delivered to Airbus and implemented in 2018 and two additional versions for different types of assembling workshops were delivered later in 2019 [A].

4.2. Enhancing collaborative capability in European supply systems

Hanse Aerospace is Germany's largest independent association of aerospace suppliers and service providers, with over 150 member companies who generate annual turnover totalling around EUR11,000,000,000. Since 2019, Hanse Aerospace has been using a software module, the Collaborative Team Formation (CTF) module, developed by Mehandjiev's team during the DIGICOR research project [6] based on earlier research [1,3,4], to enhance capability in the aerospace supply chain. The CTF module is the core of a digital platform that allows SME members of Hanse Aerospace to construct collaborations in pursuit of a manufacturing opportunity. A typical opportunity advertised by the platform is to supply manufacturers (e.g. Airbus and their Tier 1 suppliers) with an aircraft subsystem such as a side wall or lavatory. Such opportunities range in value from EUR500,000 to EUR3,000,000 over 5 years [B].

The CTF module specifically allows Hanse Aerospace to support the formation of collaborative teams among SMEs when they are bidding for opportunities and contracts, by matching SMEs based on their knowledge and skills which can together deliver an aerospace product or subsystem at various stages of procurement. A spokesperson for Hanse Aerospace stated that without access to the CTF module SMEs can only create collaborative teams using a manual exploration process which limits the number of opportunities they can bid for [B]. The spokesperson for Hanse Aerospace also confirmed that the CTF has been successful in automating the collaboration exploration process, leading to a three-fold increase in the number of collaborative opportunities SME members can access. They explain that "*this new capability increases the competitiveness of the manufacturing sector in the Hamburg region*" [B] as local SMEs can now gain access to approximately 50 collaborative business opportunities per annum, which previously were difficult for them to access alone.

Similarly, two British companies, Control 2K Limited and Sematronix Ltd, have used Mehandjiev's software to build a collaboration portal for an SME cluster in Wales. The portal enables SMEs in Wales to collaborate when bidding for contracts with large original equipment manufacturers (OEMs). The portal uses the Tender Decomposition and Matchmaking Service (TDMS) module developed by Mehandjiev during the DIGICOR research project based on earlier research [1,3,4]. The TDMS module enables SME organizations to join forces to combine the knowledge, skills and capacity to tender for complex manufacturing work. As reported by the Managing Director of the two businesses, the TDMS module and portal *"provides a new capability for Control 2K Limited and Sematronix Ltd to support the formation of collaborative teams when bidding for business opportunities"* [C]. Over 300 SMEs from Wales are using the portal through three affiliated associations (the Welsh Automotive Cluster, the Aerospace Forum and the Electronics Forum), which, the Managing Director of Control 2K attests, *"increases the competitiveness of Welsh manufacturing"* [C]. The new SME cluster portal disseminates approximately 200 opportunities for collaborative bids each year [C]. A typical bid is to supply an OEM like Ford with a car subsystem such as a suspension module and would be valued at GBP500,000 over 3 years. The Managing Director further attests that *"without access to the TDMS module through the SME Cluster portal or similar distribution platform, SME subscribers will not be eligible for the majority of these opportunities ... [and would] have to create collaborative teams using a very slow and costly manual process"* [C].

4.3. Improved efficiency and effectiveness of European Aerospace manufacturing

Airbus is one of the largest global corporations involved in designing and manufacturing aerospace products, employing over 133,000 people and creating revenues in excess of EUR63,000,000,000. Airbus has benefited from Mehandjiev's research through improvements to its production re-planning systems and its procurement and supply system.

Airbus used the manufacturing ontology and knowledge-based approach to re-planning production systems for supply disruptions, which were developed by Mehandjiev and colleagues on the ARUM project [2] and using Mehandjiev's earlier research [1,4,5]. The Research Project Leader of Systems Engineering at Airbus reports that Airbus use a version of the EPIQUA system prototyped by Mehandjiev in collaboration with CertiCon (see section 4.1) [D]. The Airbus EPIQUA system is classified as *TRL9*, which certifies it as an actual system proven in its operational environment. The Airbus Project Leader reports that *"Airbus calculations demonstrate that the re-planning system has a major economic impact on Airbus operations, saving EUR10,000,000 per annum in operating costs and allowing 10% increase of throughput"* [D]. The project result won the Airbus Best Innovation Award for 'Research to Practice' in 2018.

Airbus also benefits from the CTF module Mehandjiev developed through the DIGICOR project [6], based on earlier research [1,3,4]. The Research Project Leader of Systems Engineering at Airbus explains that *"the CTF module provides a radically new way of working by supporting rapid procurement of subsystems allowing aircraft to be personalised to the requirements of specific airlines"* [D]. Airbus calculate that this approach has resulted in a 30% improvement in speed of procurement and lower costs by 2% per personalisation [D]. The Project Leader further confirmed that Airbus is supporting the follow-up commercial exploitation of Mehandjiev's research. This includes the incorporation of the CTF module into the eFactory European Manufacturing platform [E], which is a European-wide digital platform that interlinks different stakeholders of the digital manufacturing domain to maximise connectivity, interoperability and efficiency across the supply chains.

5. Sources to corroborate the impact

[A] Testimonial letter from Chairman of the Board, CertiCon, 30.10.2019

[B] Testimonial letter from Project Manager, Hanse Aerospace, 26.10.2019

[C] Testimonial letter from Managing Director, Control 2K, 16.10.2019

[D] Testimonial letter from Research Project Leader, Airbus, 4.11.2019

[E] European Connected Factory Platform for Agile Manufacturing website, <https://www.efpf.org/>