Institution: University of Essex		
Unit of Assessment: 11 – Computer Science and Informatics		
Title of case study: Many Objective Optimised Type-2 Fuzzy Logic Workforce Allocation System enabled productivity improvements in BT's field engineering teams		
Period when the underpinning research was undertaken: Jan 2009 - Oct 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:**
Hani Hagras	Professor	January 2001 - Present
Christian Wagner	Senior Research Fellow	February 2008 - June 2011
Andrew Starkey	Senior Research Officer	October 2016 - January 2019
Period when the claimed impact occurred: 2015 – Dec 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Essex research led by Hagras improved the maintenance efficiency [text removed for publication]. The unique iPatch tool designs [text removed for publication] BT [text removed for publication] engineers' working areas to maximise productivity, minimise travel and best match skills to tasks. This increased engineers' productivity by 7%, reduced fuel consumption by [text removed for publication] *2000 metric tons of CO_2* emissions [text removed for publication]. The work also contributed to [text removed for publication] Parliamentary debates on AI.

2. Underpinning research

Optimal deployment of engineers to maximise the number of tasks the workforce completes is essential for successful maintenance and development of communications infrastructure. Consequently, engineers' work areas (patches) are designed to maximise the proportion of their time spent completing tasks. This means minimising time spent travelling between tasks by reducing distances (route planner road travel times) between them, whilst minimising variation between the work hours patches contain.

Real world decisions are often made on imprecise information. Fuzzy Logic extends Boolean Logic to handle partial truth with truth values being a real number between 0 and 1 inclusive, ranging from completely true to completely false. Fuzzy models or sets enable better handling of imprecise information and uncertainty. Type-1 FLSs (Fuzzy Logic Systems), applied to many real-world problems cannot fully handle the numerous uncertainties encountered in real world environments. Higher order fuzzy logic systems such as general type-2 FLSs, have been shown to be eminently suited to deal with such high levels of linguistic and numerical uncertainties but until recently the great computational complexities associated with general type-2 FLSs prevented their application to real-world problems. In addition, real-world workforce optimisation needs efficient and robust many-objective optimisation systems which can converge rapidly to satisfy large sets of conflicting objectives and constraints.

In 2010, Hagras introduced a pioneering theoretical approach: a complete representation framework, referred to as zSlices based general type-2 fuzzy systems [R1]. The paper was awarded by the 2010 outstanding paper in the IEEE Transactions on Fuzzy Systems. As its award citation states: "*This seminal paper allowed breakthroughs to the theory and applications of type-2*

FLSs where the paper presented a complete "modern" approach to design and realize general type-2 FLSs based on zSlices type-2 fuzzy sets". This significantly reduced both the complexity and the computational requirements for general type-2 FLSs and provided the capability to represent complex general type-2 fuzzy sets, thus allowing, for the first time, the realization of general type-2 FLSs for real world applications. This resulted in a revolutionary new wave of FLSs that can handle the high levels of uncertainty present in real world applications - something which is not possible by other means. This powerful property, in combination with their implementation and computational simplicity, yielded a powerful new generation of intelligent systems which outperform their type-1 and interval type-2 FLSs counterparts in performance.

BT's spreadsheet and map-based design of working areas (patches) for deploying engineers was extremely time consuming (in the order of months) and resulting in non-optimal results, so in 2011, Hagras began research funded by BT to optimise the strategic deployment of its engineers for better service delivery. Moreover, Hagras' unique research in Multi [R2], [P1] and Many Objective Type-2 Fuzzy Logic Based System for workforce allocation presented a novel component termed Fuzzy Dominance Rules [R3], [P2], [P3] which addressed the weaknesses in standard multi-objective optimisation systems. These systems allow the design to be "evolved" by evaluating millions of different possibilities and progressively moving towards better design. Meanwhile, moving engineers between teams to balance each team's skills pool was addressed in [R4]. The combination of Hagras' research in general type-2 FLS and many objective optimisation led to novel systems, which better handle the uncertainties and conflicting multiple objectives present in real-world workforce allocation problems to deliver a system capable of robustly satisfying the conflicting objectives in workforce optimisation.

3. References to the research [can be supplied by HEI on request]

[R1] C. Wagner and H. Hagras (2010) Towards general type-2 fuzzy logic systems based on zSlices, IEEE Transactions on Fuzzy Systems, 18, 637-660. (375 citations – February 2021). https://doi.org/10.1109/TFUZZ.2010.2045386 *This paper was awarded, by IEEE Computational Intelligence Society (CIS), the 2010 IEEE Transactions on Fuzzy Systems Outstanding Paper Award.*

[R2] A. Starkey, H. Hagras, S. Shakya, G. Owusu (2016) "A Multi-Objective Genetic Type-2 Fuzzy Logic Based System for Mobile Field Workforce Area Optimization" (60 citations – February 2020) Journal of Information Sciences, Vol. 333, pp. 390-411. https://doi.org/10.1016/j.ins.2015.09.014

[R3] A. Starkey, H. Hagras, S.Shakya, G. Owusu (2019) "iPatch: A Many-Objective Type-2 Fuzzy Logic System for Field Workforce Optimisation," (9 citations – February 2021) *IEEE Transactions on Fuzzy Systems*, Vol. 27, No.3. https://doi.org/10.1109/TFUZZ.2018.2862394.

[R4] A. Starkey, H. Hagras, S. Shakya, G. Owusu, (2016) A Genetic Algorithm Based Approach for the Simultaneous Optimisation of Workforce Skill Sets and Team Allocation. In: Bramer M., Petridis M. (eds) Research and Development in Intelligent Systems XXXIII. SGAI 2016. Springer, Cham. https://doi.org/10.1007/978-3-319-47175-4_19. *Won the Best Paper Award in the Conference.*

Patents

[P1] "Scheduling tasks to resources for a network using fuzzy logic", Granted Patent US 10261833
[P2] "Optimisation of Delivery series over Communications Network", *Patent No, PCT/EP* 3152659
[P3] *"Method and Apparatus for retrieving a data package" Patent No PCT/ EP2018/061598*

[text removed for publication]

4. Details of the impact

Workforce allocation tools developed at Essex with BT raised productivity by 7%, whilst reducing travel by 3%. Application of these tools within BT resulted in improved service to the vast majority of all UK digital network users.

PI Hagras and researchers at Essex developed the iPatch tool by applying Hagras' breakthroughs in type-2 FLSs [R1], to create a system which designs optimal work patches to minimise travel [R2] and better match skills to tasks [R4], with novel new Fuzzy Dominance Rules [R3]. Working in collaboration with BT's researchers, Hagras' research was applied to increase engineers' productivity by designing optimal work patches before publication. Practical implementation of this required close cooperation between Essex's researchers and BT's engineers, for instance the new working methods such as crossing county boundaries and change of culture, required approval of unions. iPatch soon improved performance [text removed for publication]. In a 2016 report on the iPatch [S2], BT's Change Architect explained "***It's one of a range of initiatives that's contributed to better service performance including our best PSTN [public switched telephone network] performance in five years**,".*

[text removed for publication]

BT does not just operate its own telecoms operation; it also operates the national network infrastructure via its network arm Openreach whose field force engineers maintain the copper wires that connect homes and businesses to phone and broadband. Openreach's customers include the 650+ communication service providers, which sell phone and broadband services to households and businesses [S3, p.2]. [text removed for publication] BT's subsidiary EE Limited, services approximately 32 Million connections across its mobile, fixed and wholesale communications service networks and runs the UK's biggest and fastest mobile network. EE's 4G coverage reaches 90% of the UK geography and 99% of the population. Their superfast fibre broadband service covers around 80% of the UK population, and their unlimited data allowance (ADSL) broadband service covers 98.7% of the population. As such EE is the largest and most advanced mobile digital communications company in Britain [S3, p.12-13]. Together with EE BT is one of the world's leading communications providers with for example 93% 4G coverage of the UK population [S3, p20]. [text removed for publication]

The importance of Essex's work on the iPatch was such that it was a major contribution to BT's Technology, Service & Operations (TSO) being named IT Project Team of the Year at the 2016 UK IT Industry Awards, one of the IT industry's most coveted awards [S4]. Moreover, in addition to the benefits of optimising deployment and reducing travel time already mentioned BT notes [S4] that there was no solution on the market, which took an all-round approach to field analytics. [text removed for publication] Due to the innovative work with Essex, BT also won the IEEE Computational Intelligence society 2017 outstanding Organisation [S5]. Essex and BT's collaboration won the 2015 and 2017 Global Telecoms Business Innovation (Business Service Innovation) Awards [S6]. [text removed for publication]

The iPatch research also contributed to the Scottish Parliament debates on how Artificial Intelligence can lead to future prosperity and contribute to UK growth in productivity and GDP. For instance, in the members' business debate on motion S5M-10161 on Artificial Intelligence on 18th April 2018. In particular, the SNP's Kenneth Gibson, whose name the debate was in, opens by

thanking the head of public affairs at BT and his colleague Dr Andrew Starkey *'for their excellent briefings'* [S10].

[text removed for publication]

5. Sources to corroborate the impact

[S1] [text removed for publication]
[S2] Case Study by BT, Page 26, State of the Relationship Report 2016, National Centre for Universities and Business. Available at: https://www.ncub.co.uk/reports/state-of-the-relationship-report-2016.html
[S3] https://www.openreach.com/about-us/who-we-are [Accessed: 11.03.21]; https://ee.co.uk/our-company/about-ee [Accessed: 12/06/2020], Insight into TSO, BT.
[S4] BT Today, 2016. *TSO wins award for best IT project team* [Accessed 20 June 2019]
[S5] https://cis.ieee.org/getting-involved/awards/past-recipients#OutstandingOrganizationAward
[S6] Global Telecoms Awards: https://www1.essex.ac.uk/news/event.aspx?e_id=7695 and https://www.essex.ac.uk/news/2017/06/07/bt-collaboration-wins-global-telecoms-award
[S7] [text removed for publication]
[S8] [text removed for publication]
[S9] [text removed for publication]
[S10] AI Debate, Scottish Parliament April 2018: https://www.theyworkforyou.com/sp/?id=2018-04-18.20.2