Institution: DE MONTFORT UNIVERSITY

Unit of Assessment: Computer Science and Informatics

Title of case study: Core Underpinning of Fuzzy Logic

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

The Centre for Computational Intelligence (CCI) is an internationally renowned research centre working on uncertainty modelling and optimisation. These technologies have been directly deployed by staff in the group in a range of industrial contexts:

The coaching and business improvement specialists Go M.A.D. (Make A Difference) work closely with CCI staff and have developed an online offering of their methods and techniques called iCheev. This relationship led Go M.A.D. to develop an entire technology arm for their business, which has resulted in a rapid expansion in the markets they work in.

The spin out company Venuesim has taken forecasting techniques developed by CCI directly to market. Venuesim models and predicts queue length and times at security points such as those found in airports. Venuesim has had a major impact in [text removed for publication] operations at one international airport and is now being marketed by one of the leading players in the sector, Northrop Grumman.

2. Underpinning research (indicative maximum 500 words)

The father of fuzzy logic, Lotfi Zadeh, conceived type-2 fuzzy systems in thought in 1975. Type-2 fuzzy logic is, in essence, a branch of mathematics that is conceptually appealing for dealing with and modelling uncertainty. Over the past 15 years, the field has moved from an interesting aside to a viable technology for use in complex industrial problems. This transformation has been largely driven by two individuals: Prof Robert John (CCI Director 2001-13, DMU) and Prof Jerry Mendel (Visiting Professor, DMU since 2006). Prof John's early work focused on understanding how this technology might be applied in a range of decision-making applications. It quickly became apparent that the theoretical rigour needed to underpin the application of this technology was lacking. Staff at CCI have been involved with the theoretical and practical development of this technology and have pioneered its application.

The first major contribution from Prof John came in a representation theorem in 2002 (Mendel J & John RI (2002), "Type-2 fuzzy sets made simple," IEEE Transactions on Fuzzy Systems, 10 (2), pp 117-127, DOI 10.1109/91.995115). This theorem allowed the type-2 models to be broken down into a series of simpler type-1 fuzzy models. This work is seen by many as seminal in the field, as evidenced by the number of citations to the end of May 2013: ISI Web of Knowledge - 491; Scopus-Elsevier - 683; and Google Scholar - 888. This work has continuously been classed as one of the most highly cited (top 1%) papers in its field by the ISI Web of Knowledge (Essential Science Indicators - Thomson Reuters).

This work has been carried forward in two new models, Dr Feilong Liu's (Chevron) alpha planes and Dr Hussam Hamrawi's (CCI PhD student 2007-11, supervised by Dr Simon Coupland) alpha cuts. The major obstacle to real-time operation of type-2 fuzzy logic systems, and therefore their possible deployment in a real world context, was, for a long time, the defuzzification of a type-2 fuzzy set. This is the process by which a type-2 fuzzy model, arrived at through some complex decision making process, is retranslated into real world quantities. Dr Coupland (CCI 2005 - present) invented a geometric model of this decision making process, which uses computer graphics processing algorithms to achieve real-time execution of a type-2 fuzzy logic system. This led to the first application of type-2 fuzzy logic to a control problem (robot navigation) at the centre. Prof Francisco Chiclana (CCI 2003 - present) and Dr Sarah Greenfield (CCI PhD student 2005-12, supervised by Prof Chiclana; DMU 2012 -) have since made valuable contributions in the area of defuzzification, making further efficiency improvements. The first applications of type-2 systems include robot control (Dr Coupland) and inventory management (Dr Mario Gongora CCI 2003 - present).

Staff at the CCI have driven the development of this technology to a point that has enabled industrial application, where the group has been at the forefront. The key breakthrough has been in the area of the reduction of defuzzification complexity.

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

* Towards a Framework for Modelling Variation (EPSRC EP/C542215/1) - Grant value: £145,356 (01/06/06 - 31/05/09)

* Mendel J and John RI (2002), Type-2 fuzzy sets made simple, IEEE Transactions on Fuzzy Systems, 10(2): 117-127.

* Coupland S and John RI (2007), Geometric Type-1 and Type-2 Fuzzy Logic Systems. IEEE Transactions on Fuzzy Systems 15(1):3 - 15.

- Winner of the IEEE Transactions on Fuzzy Systems Outstanding Paper Award 2007.

Greenfield S, Chiclana F, Coupland S and John R (2009), The collapsing method of defuzzification for discretised interval type-2 fuzzy sets. Information Sciences. 179 (13): 2055-2069.

Miller SM, Popova V., John RI and Gongora M (2008) Improving Resource Planning with Soft Computing Techniques. Proceedings of UKCI 2008, 37 – 42.

Gongora M and Ashfaq W (2006) Analysis of Passenger Movement at Birmingham International Airport using Evolutionary Techniques. Proceedings of IEEE-CEC 2006, 1339 – 1345.

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

Research looking at how to apply the uncertainty models described in section 2 has resulted in impacts arising from the application of the technology. This case study focusses on two examples of industrial applications. The main types of impacts are economic; creating increased profits for businesses, gaining of competitive edge and opening up entirely new markets.

Go M.A.D. (Make A Difference) is an international business improvement training and consultancy firm with a substantial client base including Cisco, 3M, Eurostar and Kraft. Go M.A.D. approached Prof John with their concept of creating a “remarkable product”; a computer system which could, in some way, mimic a life coach. Prof John headed up a KTP with Dr Coupland and Kath Roberts from Go M.A.D. to investigate this idea. The team then recruited Antonis Pavlakis as an Associate. The project culminated in the launch of the iCheev web product. The product contains a range of tools, including a coaching session where a fuzzy algorithm mimics a life coach and a creative thinking session, which heavily relies on fuzzy technologies. The launch of this product has given Go M.A.D. a new technological focus, looking at how they can deliver their product to a wider audience through complex and advanced software. The product is complimentary for anyone using traditional Go M.A.D. products and in 2011 was launched for open subscription and bulk corporate subscription. [text removed for publication]

The section of the company (GO M.A.D. Technology, which did not exist before the KTP) now employs four full time and three part time members of staff.

The product represents a step change in their business model. A purely online product means the number of customers the company can coach is not limited by staff level, significantly increasing the company’s capacity for life coaching. The product is being used by clients in a number of countries, allowing the results from DMU’s research to serve an international client base. The focus of the product is to help people understand and realise their personal and professional goals, enhancing both quality of life and having impacts further down the supply chain.

Venuesim, a spin-out company based at DMU, was incorporated in 2009 to supply real-time models of customer movement through large venues and represents a direct exploitation of forecasting technologies developed by the CCI. The company has attracted customers from the

airport industry. Venuesim predicts passenger flows and queue times over the short, medium and long term, enabling airports to predict queue and dwell time. These predictions have been shown to be within 2% of actual passenger flows. The key improvement provided by the technology is that it allows management to modify staffing levels at key places (check-in desks, security, etc.) and to optimise the retail dwell time of the passenger. This means the airport retail outlets have optimal exposure to customers at minimum staffing costs and passengers benefit from experiencing reduced queuing times at security, enhancing the passenger experience.

The first airport to adopt Venuesim was East Midlands Airport (EMA). EMA began with a trial of Venuesim in April 2010 and has used the system as a fully paid-for commercial product since September 2010.

[text removed for publication]

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

Evidence for the economic impact of job creation and business transformation at Go M.A.D. Ltd can be verified by the General Manager of Go M.A.D. Technology Ltd, or by the Managing Director of Go M.A.D. Ltd (contact details provided).

Confirmation of the creation of the spinout company Venuesim Ltd can be provided upon request as a redacted copy of the relevant paperwork from DMU legal services.

Confirmation that Venuesim is used commercially at East Midlands Airport (and confirmation of how it is used) can be given by the Head of Customer Services (contact details provided)

Confirmation of the agreement for Marketing and providing Venuesim's products through Northrop Grumman's Park Air Systems can be sought from their Senior Market Development Manager, and their Product Manager - Airport Systems, can provide details on agreement and market significance.

Evidence of the impact on the industry can also be seen in reports in high profile trade publications and invitations to the team to speak at prestigious events For example, please see the following links (accessed 18/10/13):

- http://www.airport-technology.com/features/featureartificial-intelligence-predictive-modelling-airport
- http://investor.northropgrumman.com/phoenix.zhtml?c=112386&p=irol-newsArticle&id=1742214
- http://www.internationalairportreview.com/10481/airport-news/northrop-grumman-highlights-airport-realtime-collaboration-capabilities-at-airport-itt-conference-munich/